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REVIEW AND RECOMMENDATIONS FOR THE INTERAGENCY SHIP STRUCTURE C--ETC(U)
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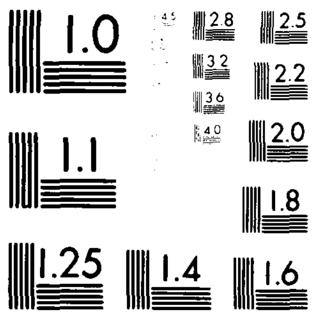

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REVIEW AND RECOMMENDATIONS

for the

INTERAGENCY

SHIP STRUCTURE COMMITTEE'S

FISCAL 1981 RESEARCH PROGRAM

and

FIVE-YEAR RESEARCH PROGRAM PLAN.

APR 1980

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(9) Final rept.

A Report Prepared

by the (15) DOT-CG-80356-A

SHIP RESEARCH COMMITTEE

of the (12) 116

Maritime Transportation Research Board

Commission on Sociotechnical Systems

National Research Council

(11) Mar 80

National Academy of Sciences
Washington, D.C.
March 1980

406356

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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This report was prepared for the interagency Ship Structure Committee, consisting of representatives from the Military Sealift Command, the U.S. Coast Guard, the Naval Sea Systems Command, the Maritime Administration, the American Bureau of Shipping, and the U.S. Geological Survey, and is submitted to the Commandant, U.S. Coast Guard, under provisions of Contract DOT-CG-80356-A between the National Academy of Sciences and the Commandant, U.S. Coast Guard, acting for the Ship Structure Committee.

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ABSTRACT

The Ship Research Committee (SRC) of the National Research Council provides technical services covering program recommendations, proposal evaluations, and project advice to the interagency Ship Structure Committee (SSC), composed of representatives from the U.S. Coast Guard, the Naval Sea Systems Command, the Military Sealift Command, the Maritime Administration, the American Bureau of Shipping, and the U.S. Geological Survey. This arrangement requires continuing interaction among the SRC, the SSC, the contracting agency, and the project investigators to assure an effective program to improve marine structures through an extension of knowledge of materials, fabrication methods, static and dynamic loading and response, and methods of analysis and design. This report contains the Ship Research Committee's recommended research program for five years, FY 1980-1984, with 13 specific prospectuses for FY 1981. Also included is a brief review of 24 active and 6 recently completed projects.

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The SHIP STRUCTURE COMMITTEE is constituted to prosecute a research program to improve the hull structures of ships and other marine structures by an extension of knowledge pertaining to design, materials and methods of construction.

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Secretary, Ship Structure Committee

SHIP STRUCTURE SUBCOMMITTEE

The SHIP STRUCTURE SUBCOMMITTEE acts for the Ship Structure Committee on technical matters by providing technical coordination for the determination of goals and objectives of the program, and by evaluating and interpreting the results in terms of structural design, construction and operation.

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INTRODUCTION

Organizational and Administrative Matters

Establishment of Committees

Since 1946, the National Research Council's Ship Research Committee (SRC) and its predecessors have been rendering technical services to the interagency Ship Structure Committee (SSC) in developing a continuing research program, sponsored by the SSC and funded collectively by its member agencies, to determine how marine structures can be improved for greater safety and better performance without adverse economic effect.

The SSC was established in 1946 upon recommendation of a Board of Investigation, convened by order of the Secretary of the Navy, to inquire into the design and methods of construction of welded steel merchant vessels. As that investigation was brought to a close, several unfinished studies and a list of worthy items for future investigation remained. The Board of Investigation recommended that a continuing organization be established to formulate and coordinate research in matters pertaining to ship structure. Figure 1 shows the relationship of the

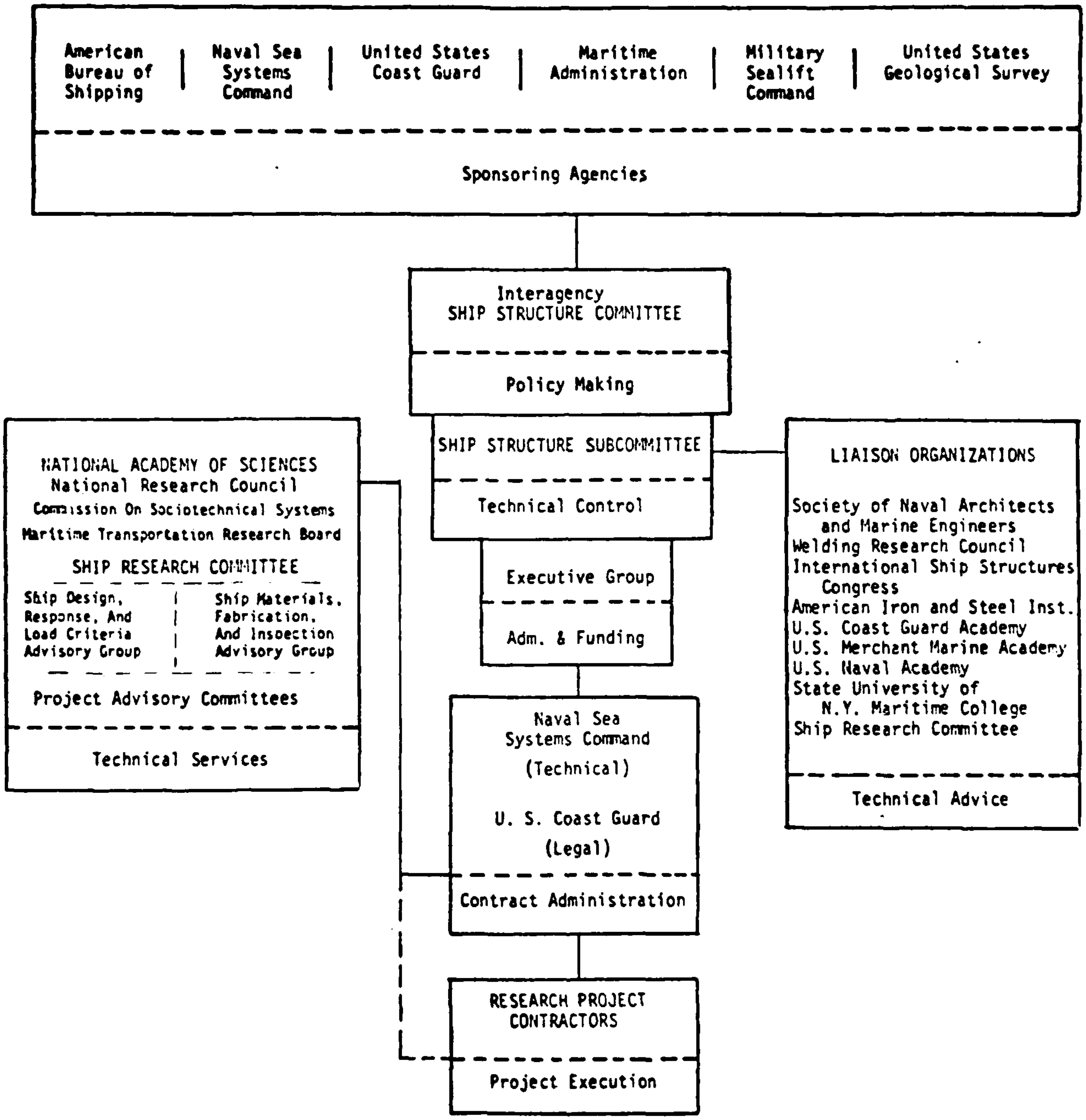

FIGURE 1. SHIP STRUCTURE COMMITTEE ORGANIZATION CHART

various organizational entities involved in the work of the SSC.

Committee Composition and Responsibilities

The SSC is composed of senior officials, one each, from the U.S. Coast Guard, the Naval Sea Systems Command, the Military Sealift Command, the Maritime Administration, the American Bureau of Shipping, and the U.S. Geological Survey.

The SSC formulates policy, approves program plans, and provides financial support through its member agencies for the research program.

A maximum of four representatives from different divisions within each agency meet periodically as a Ship Structure Subcommittee (SSSC) to assure achievement of program goals and to evaluate the results of research projects in terms of structural design, construction, and operation.

Members of the SRC and its advisory groups are selected for their competence and experience in relevant areas from academic, governmental, and industrial sources. The members serve as individuals, contributing personal knowledge and judgement, and not as representatives of organizations where they are employed or with which they may be associated. The SRC's responsibilities to the SSC are to assist in setting technical objectives; define research projects; recommend research priorities; evaluate proposals;

review the active projects, including progress and final reports; and prepare summaries of related research work.

Research Program Development

It has become established procedure to conduct a September joint meeting of members of the SRC, the SSSC, and the Hull Structure Committee of The Society of Naval Architects and Marine Engineers (SNAME) to review current research needs and suggestions for future research projects. Each agency of the SSC prepares a memorandum describing its discernment of needed research. These memoranda are provided to all participants in advance of the meeting.

Seven panels are set up, one for each goal in the five-year plan, with representation from each agency and SNAME assigned to each panel. The panels meet in round-table discussions led off by members of the SRC. These discussions produce, in varying degrees, expressions of commonality among the agencys' interests in research needs. The panel sessions are held consecutively so that all other participants can observe and join the discussion as appropriate.

A few weeks later at the Fall meeting of the SSC, the SRC presents its preliminary reactions to the suggestions from the joint meeting and discusses with the SSC project areas for which prospectuses could probably be developed.

Project Development

The suggestions contained in these agencies' memoranda, those brought out at the joint meetings, those generated within the SRC and its Advisory Groups, those contained in the International Ship Structures Congress proceedings, and those obtained from other sources are carefully studied for applicability to the SSC research program in terms of need, immediacy, program continuity, and likelihood of successful and meaningful completion. A prospectus is drafted by the appropriate SRC Advisory Group for each of the research projects that is considered worthy of SSC support. These are reviewed and ranked by the SRC and included in an annual report to the SSC. The SSC determines which projects will be supported. The prospectus becomes a part of the Request for Proposal (RFP) and subsequently a part of the contract document. The RFPs are prepared and issued through the cooperative effort of the Naval Sea Systems Command, which provides technical contract administrative support services, and the U.S. Coast Guard, which handles the actual business of contracting. The RFPs go to research laboratories, universities, shipyards, and other organizations and are advertised in the *Commerce Business Daily*.

Proposal Evaluation Procedure

An organization interested in doing work submits a proposal and an estimated cost. The USCG Contracting Office

removes the cost data and transmits the technical data in the proposal to the SRC for technical evaluation and review.

The SRC Executive Secretary verifies that no SRC or Advisory Group member or affiliated company is represented in the proposals. This important step avoids conflict of interest. The SRC chairman selects an ad hoc proposal evaluation committee that generally consists of the Chairmen of the SRC and the pertinent Advisory Group, two or three other members from either the Advisory Group or the SRC, the Secretary of the SSC, the Contract Officer's representative, and frequently one or two SSC liaison members.

The proposals are evaluated for the analysis of the problem, the proposed solution, the assessment of the scope of the effort, and the adequacy of the organization and personnel.

After the evaluation committee judges the technical merit of the proposals, ranks them, and comments on any shortcomings, the USCG Contracting Officer forwards the technical evaluation and cost data to the SSC. The SSC considers the proposals together with the technical evaluation and costs and sends its recommendations to the Contracting Officer, who, following routine procurement practices, then awards a contract.

Annual Report Summary

Status and progress of SRC-SSC research activities are reported annually. The annual report includes SRC

recommendations to the SSC for continued and new research to be funded during the ensuing fiscal year.

This, the latest in the series of annual reports, covers research activities during fiscal year 1980, sets forth recommendations for the SSC's fiscal year 1981 research program, and outlines a five-year research planning program.

Five-Year Research Program Plan Development

A continuing program of research in marine structures must be guided by a perception of the directions in which marine activity is moving. The FY-1981 program and the associated five-year plan are aimed at producing programs that will support emerging needs of marine development as best they can now be perceived. Some of the specific areas addressed in the program are discussed in the following paragraphs.

Safety and Reliability

Uncertainties are unavoidable in any engineering design; such uncertainties could be associated with the inherent randomness of the physical phenomena or with the errors of analysis and prediction. Probabilistic methods and concepts are the appropriate tools for analysis and assessment of uncertainties. For these reasons, probabilistic reliability concepts necessarily pervade all areas of engineering analysis and design--from quantitative estimation or evaluation of safety, to development of criteria for design to achieve a desired level of safety,

including reliability against fatigue failure as well as safety against extreme load.

Use of probabilistic methods for measuring reliability, however, should not necessarily require changes in the existing formats for design and analysis. Indeed, the principal role of probabilistic methods is to establish required safety factors or allowable stresses for use with usual deterministic design procedures.

The key element in introducing available probabilistic methods for safety analysis and criteria development is assessment of realistic measures and sources of uncertainty underlying current methods of design. An SSC project to examine the uncertainties associated with ship structural design has been approved.

Probabilistic methods can also be used to improve inspection and maintenance procedures. In particular, an inspection interval and level of maintenance and repair to ensure a desired level of safety and reliablility may be developed in probability terms.

Ultimate Strength of Ship's Hull Girder

The design of a ship structure to resist wave bending loads has been and, to a large degree, continues to be based on design standards using quasi-static loads. Scantlings are selected to give certain calculated stress levels, but these do not relate to actual stress levels experienced. Rather, they provide a basis for comparison of new designs with previous designs and of identifying

successful or unsuccessful performance with designed stress levels. However, neither the load conditions nor the calculated stresses give a realistic picture of the ultimate loading on or strength of the hull girder.

A long-term goal of work in this area is to provide a method for realistically estimating the collapse strength of a hull girder, so that scantlings can be assigned to give some identified margin of strength against some realistic extreme wave loading or, conversely, some acceptably small probability of failure.

There is much uncertainty regarding the ship response aspect of ultimate hull girder strength estimation about how to predict compressive failure modes. A number of current analytical and experimental research efforts, in the United States and abroad, should produce improved means of estimating hull girder strength, taking into account the post-buckling strength of hull girder elements. A project to develop a procedure for predicting compressive failure modes and computing hull girder failure bending moments may be appropriate when the results of some of the ongoing research are available. This ultimately could be combined with wave spectral models to provide a realistic approach to hull girder design.

Wave Spectra

Much work has been done on wave spectra and the prediction of extreme values of wave heights based on long-term observations. Out of this work, under a number of

sponsors worldwide, ultimately should come the ability to describe the seaway in terms of wave height, frequency, and directionality in spectral form and the long-term probability of occurrence for specific geographical areas. Obviously, this is not a simple concept nor one that is likely to be achieved completely in the foreseeable future. It does, however, now appear realistic to begin developing standard families of wave spectra from available data for design use, and an effort is proposed to implement this.

High-Performance Craft

Surface-effect ships (SES) and air-cushion vehicles (ACV) are craft supported on an air cushion. The ACV is amphibious by virtue of a flexible seal around its entire periphery and is propelled by aircraft type propellers. The SES generally has rigid sidewalls, with flexible seals at bow and stern; consequently it is not amphibious. It can be propelled by water jets or conventional water propellers.

The hulls of both craft have relatively large surface area for their size and weight, and structural loadings are low. Generally, therefore, aluminum is the construction material used. This results in both high strength to weight ratio and low density. Applications vary between (a) high-strength, corrosion-resistant, aluminum alloys, which achieve minimum weight but require costly mechanical fastening and introduce difficult sealing problems and (b) weldable, corrosion-resistant aluminum

alloys, which are much cheaper to fabricate but are not as efficient structurally.

Neither of these classes of aluminum alloys has seen significant application in the aerospace industry, since the preference there is for much higher strength alloys, which are not sufficiently corrosion resistant for marine applications. Consequently, there is a lack of adequate material information for marine design purposes. In particular, data on low-stress, high-cycle fatigue, in the salt water and salt spray environment, for both parent material and welded or mechanical fastenings, as well as fracture data for assessment of crack growth and crack criticality are lacking. These data are costly and time-consuming to obtain. Each specimen requires a large amount of test time when high-cycle data are required. In addition, there are a large number of parameters (geometric, environmental, stress-state, processing, inspections, etc.) that can affect results and whose effects must be determined.

Hydrofoils combine a relatively lightly loaded hull, which is typically aluminum, with a highly loaded foil system, typically of high-strength stainless or coated steels. The hull requirements are similar to those described for the ACV, but the foil systems introduce highly loaded local structures that justify using high-strength steels or titanium.

Material Characterization

The extensive material characterization background built up by the aerospace industry for aircraft and space vehicle applications is of limited use, and there is a need for data for marine application of these materials. Materials of interest include high-yield-strength steels, aluminum alloys, stainless steels, titanium alloys, and, in a more limited way, new material forms such as composites and sandwich construction.

The critical data needs for all these materials are primarily high-cycle fatigue data and fracture data but include effects of welding and joining, the effects of the marine environment, significance of the particular nondestructive inspection methods used with the joining process, and effects of local geometry involving stress distribution and stress gradient.

Composite materials, ranging from fiberglass to graphite-reinforced epoxy, constitute another class of materials of interest for high-performance craft. These, more than aluminum, stainless steel, or titanium alloys, represent an even wider departure from the conventional carbon steel. Composites introduce many parameters, in addition to those already mentioned, whose effects on fatigue and fracture are required. Such parameters include varieties of reinforcements and matrix materials, large varieties of reinforcing filament orientations, and the sensitivity of these materials to many processing variables.

Research in the areas mentioned should substantially enhance the introduction of more efficient materials into marine structures with corresponding improvements in performance, reliability, and cost effectiveness of high-performance craft.

In addition to the proposed material characteristics data and evaluation survey for high-performance craft, use of concrete in marine structures is being reviewed, evaluation of anti-fouling Cu-Ni-clad hull steels for use in large ship construction is being recommended, and steels now used in non-marine applications in the Arctic are being considered for possible marine use.

Strain Rates

Past work indicates little correlation between laboratory-developed fracture-toughness criteria and actual service experience. The most likely cause of the discrepancy is the difference in impact-type laboratory tests used to evaluate toughness (e.g., Charpy V-notch) and the relatively less rapid in-service strain rates.

To put the issue of strain rate in perspective, it is useful to consider the following basic definitions and typical ranges of values. Strain (ϵ) is elongation per unit length, measured in the laboratory or in the field as the difference between final extension and original length divided by the original gage length between the two points, and is a dimensionless quantity, i.e., inch/inch. Strain rate ($\dot{\epsilon}$) is strain per unit time, $d\epsilon/dt$ (inch/inch/second).

Ship steel toughness is measured in the laboratory by tests performed at a range of strain rates. The well-known Charpy V-notch impact test is at the upper end of the range with strain rates of the order of $\dot{\epsilon} \approx 10^2$. At the lower end are fracture appearance tests, which are typically done at quite low strain rates, i.e., of the order of 10^{-3}. Transition temperature curves, which are a common measure of toughness for ship steels, can be displaced by 100°F or more, depending on the testing method. This displacement is attributable to the strain rates at which the tests are carried out, as shown in Figure 2.

Ship strain rates in locations of interest are thought to be related to wave bending frequency or natural

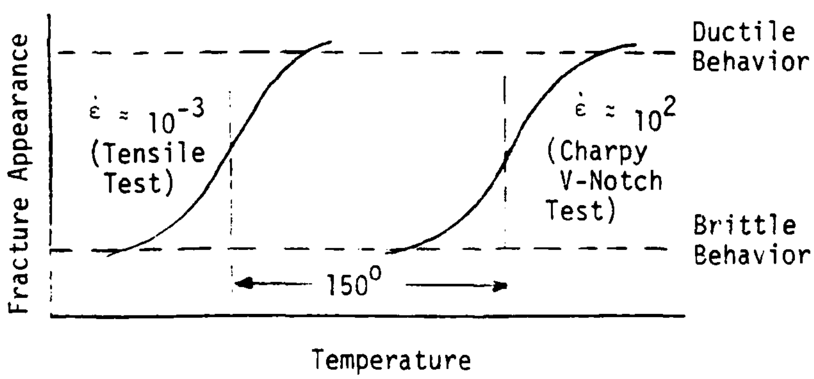

FIGURE 2 EFFECT OF DIFFERENT STRAIN RATES ON MATERIALS

hull frequency. They produce strain rates on the order of 1 and 10^{-1}, respectively, which lie somewhere between the extremes of values associated with the usual laboratory tests for evaluating toughness.

Because toughness is an expensive characteristic in steels, it is important that toughness requirements be realistic and be neither over- or under-specified. Very little information about typical shipboard strain rates is available, and efforts are now being recommended to gather the needed data.

Five-Year Research Program Plan

The five-year research planning program in Table I builds on current activities and places them in perspective with contemplated work in various project areas during the next four years. The project areas are classified under the following seven goals of the SSC:

Advanced Concepts and Long-Range Planning
Loads Criteria
Response Criteria
Materials Criteria
Fabrication Techniques
Determination of Success/Failure Criteria (Reliability)
Design Methods

Work in each of these areas includes adequate verification procedures to ensure that sound recommendations are made. The thrust is to expand the existing base of knowledge in each area that will result in design methods,

fabrication procedures, and materials for safer and more efficient marine structures.

It is intended that the program be dynamic and flexible so that it can be modified and redirected to be responsive to changing circumstances.

TABLE I

SHIP RESEARCH COMMITTEE'S RECOMMENDATIONS FOR CONTINUING FIVE-YEAR FISCAL RESEARCH PLANNING PROGRAM FOR THE SHIP STRUCTURE COMMITTEE

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
	GOAL: I - ADVANCED CONCEPTS AND LONG-RANGE PLANNING				
Overall research planning studies	Conduct joint meeting to develop Agencies' & Societies' present and planned research work	→	→	→	→
	Examine new formats for presenting this five-year research plan.				
	Examine current marine structural research status (all agencies). Develop an overall outline to accomplish general objectives.	→	→	→	→
	Conduct project to develop a coordinated plan including specific proposed technical approaches for each section; provide detailed references to past & existing work both domestic & foreign, & provide cost estimates & a cost-benefit ratio. (SR-1259)*	Conduct workshops to gain additional input & priorities to the coordinated plan. (SR-1259)*	←	(Commence following research plan.)	→

* (SR-1259) designation refers to projects described in the yellow pages of this report.

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TABLE I (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
GOAL: I - ADVANCED CONCEPTS AND LONG-RANGE PLANNING (Continued)					
Conduct Technical Symposium	Review Vibration Symposium Results & Recommendations				
		Begin preparations for 1982 Symposium on Response of Marine Structures to Extreme Loads.	Conduct Sumposium	Review Symposium Results	
					Begin preparations for 1985 Symposium
Advanced & Long-Range Planning of Materials & Their Applications: Concrete	Conduct a survey of construction & operating experience of marine concrete structures. Develop the basis for a research program to provide guidance & recommendations to designers & builders of floating structures. (SR-1270).	Complete SR-1270	Evaluate recommendations for follow-on research.	Begin research, e.g., an understanding of the fatigue requirements & performance of large concrete marine structures.	Continue specific research as indicated by previous work.
Arctic Materials	Institute program to survey material property data for applications in Arctic conditions. (SR-1278)	Review results and include new materials into other ongoing material property studies.	Undertake material research relevant to Arctic energy development.	Continue research	Review results in terms of actual application.

TABLE I (Continued)

GOAL; I - ADVANCED CONCEPTS AND LONG_RANGE PLANNING (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
Cu-Ni Clad Steels	Develop a work plan for using SSC-289, A Method for Economic Trade Offs of Alternate Ship Structural Materials on Cu-Ni clad steel hulls.	Institute project for the economic analysis and technical awareness of Cu-Ni clad steels (81-12)*	Complete and review project results.		
			Consider program to examine other materials.	Initiate and carry out such projects.	Continue effort.
Application of Materials for High Performance Marine Structures		Conduct study to identify data requirements and necessary test program to examine material data requirements for high-performance craft. (81-7)	Conduct experimental program to obtain required material data for high performance craft.	Continue high-performance craft material data gathering.	Complete experimental program and results.
Collisions and Groundings		Develop grounding loads & analysis logic for a computer program (SR-1272 or 81-9)	Develop grounding loads & analysis computer program.	Develop logic to *incorporate dynamic* loading .	
			Develop prospectus for model simulation of groundings according to various scenarios & associated model experiments.	Investigate the common technologies and engineering analysis applicable to both ship collision and grounding problems.	Investigate interim design proposals to limit grounding damage.
			Develop analytical procedures for low-energy collision & grounding including studies by ship type.	Compare & modify collision stranding theory.	Develop generalized design guidelines for low-energy collisions & energy absorption criteria & parametric studies for various structural configurations.

* (81-00) designation refers to projects recommended in the green pages of this report.

TABLE I (Continued)

GOAL: II - LOADS CRITERIA

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
Static/Quasi Static, Thermal, (Diurnal, Cryogenic, Hot) Cargo, Ballast, Fuel, Cargo Distribution, Light Weight of Ship, Ship's Induced Wave, ice, Impact, Crushing.	Complete project to review literature, ship operations, & ice histories of navigable waterways for ice loadings on ships. Compare with present ice strengthening of ships. Indicate were additional information required. (SR-1267)	Review ice project results.	Develop plan to obtain necessary data. Monitor SNA&ME's Ice Symposium in Toronto Canada.	Implement ice loading plan.	Continue to carry out ice loading plan.
		Develop program to obtain still-water bending moment data for typical ships. (SR-1282)	Begin program to obtain still-water bending moment data for typical ships.	Complete data collection program.	Prepare Design Load Profiles. Recommend modifications to Design Criteria.
Dynamic Cargo Liquid, Sloshing, Dry, Shifting Load, Pumping Problems, Mobile Cargo (Wheeled Vehicles)	Publish SR-1251 results on liquid dynamic load criteria in slack cargo tanks for LNG carriers.	Review & correlate current model & full-scale non LNG liquid slosh data. Conduct model tests to complete correlations for various fill depths, geometry, & excitation parameters. (81- 3)	Evaluate significance of impulsive slosh loads in full-scale liquid tanks. Develop prediction of wall response to impulsive slosh pressure. Recommend design guidelines for tank walls.	Develop general purpose curves & tables for use in design of liquid cargo tanks.	
		Review Navy design data sheets on wheel loadings.	Review & categorize types of shifting cargo loads, & establish priority of dynamic load problems. Develop plan for analysis of high-priority items.	Conduct analyses and tests to establish dynamic loads & corresponding structural responses to shifting cargo under typical operational conditions.	Develop curves & tables for ready use in design for dynamic loads due to shifting cargo.

TABLE I (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
		GOAL: II - LOADS CRITERIA (Continued)			
Propeller-Induced Vibrations	Evaluate SSC 292, Report on Ship Vibration Symposium '78, and formulate a research plan.				
Wave-Induced Wave Records/Spectra, Local Ship Wave Instrumentation, Slamming, Green Water, Steady State.	SRC to organize an August 1980 ad hoc group of the various principal investigators to provide guidance and planning for follow-on investigations and analysis of the several projects now underway by USCG, MarAd, ABS and SSC on verification of advanced ship motions.	Develop wave spectra for design purposes. (81-4)	Collect & Analyze wave information and develop long-term wave statistics necessary for fatigue failure analysis.	Continue collection and analysis of wave information.	Develop a method to statistically estimate the combined wave-induced bending and torsional loads necessary to perform structural failure analysis.
	Review USCG Great Lakes project utilizing portion of full-scale slam instrumentation package.	Continue Review of USCG Great Lakes project.	Develop prospectus for full-scale slam instrumentation and wave-meter data collection.	Analysis of impact pressure and velocity. Correlate trials data with model experiments and theory. Conduct full-scale slamming, bow-flare, and green water impact trials to collect data using the instrumentation developed under previous SSC project.	Develop technology to predict impact loads for ship design consideration.
	Survey and analyze experience of vessels encountering extreme waves. (SR-1281)	Complete SR-1281.	Review SR-1281 results.		

TABLE I (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
		GOAL: II - LOADS CRITERIA (Continued)			
Wave-Induced...	Formulate hydrodynamic model for predicting ship motions and wave loads above and below the still-water line. (SR-1277)	Develop a motions and and distributed loads computer program accounting for hull shape above and below the still-water line.	Complete SR-1277:	Review SR-1277 results.	
		GOAL: III - RESPONSE CRITERIA			
Vibrations Analysis & Prediction, Steady State (Springing, Bending, Torsion) Transient, (Whipping), Measurement/Verification	Collect & evaluate ship structural damping data and indicate test program to verify design extension. (SR-1261)	Initiate project on hydrodynamic damping. (81-11)	Continue 81-11, review interim project report before commencing the development for full-scale test plan.	Evaluate 81-11 results, and conduct full-scale tests.	Evaluate full-scale test results.
Stress, Deformation Analysis & Prediction, Measurement/Verification, Steady State, Transient, Static Thermal.	Calibrate CORT instrumentation for full-scale pressure measurements. (SR-1275)	Review SR-1275 data and continue data collection.	Evaluate SR-1275 results.		
	Initiate pressure distribution model tests in waves to determine pressure loads (SR-1271).	Complete pressure distribution model tests. Use ABS computer program to calculate pressure distribution corresponding to model tests.	Evaluate model, full-scale, and computer results for pressure distribution.	Proceed with necessary adjustments to testing techniques or to computer program.	
	Continue collection and reduction of SL-7 scratch-gage data. (SR-1245)	Complete SL-7 scratch-gage data collection.	Continue scratch-gage extreme stress data collection on SL-7, if necessary, or gather data on ships of another class.	Continue scratch-gage extreme stress data collection, if necessary.	Continue scratch-gage extreme stress data collection, if necessary.

TABLE 1 (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
		GOAL: III - RESPONSE CRITERIA (Continued)			
Stress/Deformation..	Evaluate scratch gage data and develop guidelines on when to remove gages. (SR-1268)	Review SR-1268 results.			
	Begin evaluating SL-7 research program results and recommend improvements, broadening or restricting data gathering. (SR-1279)	Complete SR-1279.	Develop recommendations for future full-scale test programs.		
	Establish deflection guidelines for ships in relation to main machinery alignment tolerances. (SR-1266)	Complete SR-1266.	Fabricate and test large-scale models or instrument actual ship hull elements to verify guidelines.	Examine large-scale hull element test results.	
		Develop procedure to measure shipboard strain rates. (81-1)	Initiate program to gather strain-rate data and review applicability to offshore structures.	Continue gathering strain rate data on another class of ships and offshore structures.	Evaluate strain-rate as a factor in design.
		GOAL: IV - MATERIALS CRITERIA			
Fracture and Fatigue Control	Investigate fatigue behavior in terms of measured load spectra developed from ship strain measurements. (SR-1254) Evaluate available procedures for evaluation and selection of fabricated structural details under cyclic-loading conditions. Classify the' vulnerability of ship	Conduct experimental work to verify the classification procedure selected in the previous work. Conduct experimental work to classify the vulnerability of details whose behavior is not known. (SR-1257)	Develop fatigue guidelines and design procedure in the selection of ship details. Include effects of weld geometry and residual stresses.	Review safety analysis of ship structural details against fracture and fatigue failures. Develop reliability based inspection and maintenance schedules to insure safety against brittle fracture.	Develop an overall fracture-control plan for ship st structures that incorporates both fatigue and fracture behavior of fabricated ship details and a reliability analysis.

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TABLE 1 (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
		GOAL: IV - MATERIALS CRITERIA (Continued)			
Fracture and Fatigue..	details under cyclic loading using the best available procedure. (SR-1257)				
		Critically review fracture-control plans for fixed offshore platforms which include materials, properties and designs for increased reliability in hostile marine environments. (81-8).	Review results and indicate research in needed areas.	Initiate important projects.	Continue effort.
	Initiate a program to use long-term corrosion fatigue data in the design of offshore structures and ships. (SR-1276)	Continue SR-1276.	Review program, provide an initial guide for a fatigue control plan in in offshore structures.	Begin long-term corrosion fatigue tests.	Continue testing.
	Review ABS-Battelle's fatigue program on Great Lakes Bulk Carrier.				
	Complete fracture toughness characterization of HAZ'S in ship steel weldments. (SR-1238)				
	Evaluate fracture guidelines for ship steels and weldments from information developed in recent SSC projects. (SR-1265)				

TABLE I (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
		GOAL: V - FABRICATION TECHNIQUES (Continued)			
Improved Weld...		Review Welding Research Council's report on distortion control in aluminum weldments and its applicability to marine structures.			
Underwater Welding		Initiate project to examine performance of of underwater and water-backed welds. (81-2)	Conduct necessary testing and evaluate program.	Review project results.	
Design of Welded Ship Details	Review structural detail report prepared for MarAd	Review Navy detail manual when completed and current ASTM work underway.			
Effects of High-Deposition Welds-Improved HAZ	Identify critical controls in the development of improved weldments using a variety of high-deposition rate processes and procedures. (SR-1256)	Determine whether new materials or processes provide adequate service life using fracture and fatigue tests. Consider using test methods developed in SR-1238 to evaluate welding procedures.	Provide an initial guide for use on high-deposition rate weld processes in ship construction.		
	Continue to monitor MarAd's program on improved ship steels.	Continue to monitor MarAd's program on improved ship steels.			
Structural Details	Complete examination of different sound and failed structural ship details. (SR-1258)				

TABLE I (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
		GOAL: IV - MATERIALS CRITERIA (Continued)			
Fracture ...			Initiate program to conduct research in area of elastic-plastic fracture.	Continue to gather information from studies. Apply results to actual application experience.	Develop elastic-plastic fracture design methods.
				Evaluate full-scale strain-rate shipboard data in light of proposed fracture guidelines.	Modify guidelines if necessary.
Corrosion Control	Start a survey and life-cycle cost study to identify the most economical corrosion control systems in the existing and projected economic and regulatory climate. (SR-1269)	Decide on the basis of of cost study results, whether or not a more rational approach to corrosion margins is required.	Initiate study or experimental program.	Make recommendations for changes in design methods.	
		GOAL: V - FABRICATION TECHNIQUES			
Improved Weld Quality Guides	Review NDI practices used for heavy-section castings, forgings and weldments. Prepare an interpretive report of the procedures and acceptance limits applicable to ship components. (SR-1255) Review MarAd work on weld quality levels for structural integrity in ships.				

TABLE I (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
		GOAL: VI - DETERMINATION OF FAILURE CRITERIA (RELIABILITY)			
Failure Modes and Safety Analyses	Complete review of available techniques for safety analyses. (SR-1241)	Analyze and assess major uncertainties in current ship hull design. (SR-1280)	Evaluate reliability in terms of failure probability or safety index for major failure moves for specific types of ship design according to current requirements.	Formulate risk-related or probability-based criteria for design of ship hulls against specific modes of failure; this may include (a) ships of conventional (steel) material; (b) ships of future marine material, e.g., composites.	Undertake analysis of past structural failure of ships to support reliability analysis of ship hull safety.
			Initiate project to study successive transfer of compressive loads for scenario of failure.	Complete and evaluate project results.	
In-Service Monitoring		Develop guidelines to conduct in-service structural inspection of ships. (81-6)	Review results and begin similar program for offshore structures.		
		GOAL: VII - DESIGN METHODS			
Design Procedures Efficiency, Economics, Optimization, Test and Evaluation, Preliminary Design	Complete SR-1262 to determine the ultimate strength of a ship hull girder.	Review procedure for determining ultimate strength under combined vertical, lateral, torsional loads.	Develop procedure for predicting transverse plane motions and transverse and torsional loads.	Fabricate large-scale hull girder model and test to failure, measuring stresses and deformations and comparing with calculations.	Evaluate possibility of using ultimate strength in hull girder design roles..

TABLE I (Continued)

PROJECT AREA	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
		GOAL: VII - DESIGN METHODS (Continued)			
Design Procedures	Review existing optimization techniques and develop a computer program for preliminary design. (SR-1274)	Complete and review preliminary design program.			
			Develop preliminary design procedures for ends of ships to avoid vibration and slamming damage.	Verify the preliminary design procedures for ends of ships.	
	Complete supplementary monograph to SHIP STRUCTURAL DESIGN CONCEPTS (SR-1263)				
		Develop dry docking analysis program. (SR-1273 or 81-10)	Complete and review dry-docking program results.		
		Initiate project to develop a guide to structural modeling for numerical analyses. (81-13)	Complete and review project results.		
		Initiate project to examine minimum size fillet welds for design. (81- 5)	Evaluate fillet weld sizing results and suggest new guidelines.		
		Examine AISI-sponsored project results on reinforced openings in steel containment vessels for relevancy to ship structures.			

FISCAL 1981 PROJECT RECOMMENDATIONS

Table II lists the projects proposed for the 1981 Fiscal Year in priority order, based on the averaged judgements of the SRC membership that included the recommendations of the Advisory Groups. Prospectuses for these projects are presented in the same order.

As in past years, more projects are included than are likely to be funded with the anticipated support. However, the possibility of greater support, the need of the SSC for a reasonable number of projects from which to select, and the possibility that some projects not initiated in Fiscal Year 1981 could well be included in the program for the following year, suggest that the preparation of the additional prospectuses is a useful service.

The man-hour figures are intended to indicate the approximate level of effort (cost) that is to be expended on the project.

TABLE II - RECOMMENDED PROJECTS FOR THE 1981 FISCAL YEAR

NOTE: Priorities are given in descending order of ranking.

DETERMINATION OF THE RANGE OF SHIPBOARD STRAIN RATES SRC Priority 81-1

Long-Range Goal: Response Criteria

OBJECTIVE

The objective of this project is to develop a test program to obtain representative strain rates in ship hull structures.

BACKGROUND

Most fracture toughness data and related studies have dealt with slow loadings, as in the case of static tensile tests, or very rapid loadings, such as in Charpy V-notch tests. From these tests we have learned that structural steels are sensitive to the rate at which the load is applied or, more precisely, the strain rate--defined as the change in strain with time. For example, the yield strengths and transition temperatures increase with increasing strain rate.

In order to relate the behavior of ship steel structures to dynamic tests in a meaningful way, it is necessary to know the typical range expected in shipboard strain rates. In the determination of shipboard strain rates, it is recognized that both the level of strain and duration of loading (time) may change depending on the sea state and structural location. Regardless of the value of each (strain or time), it is most important to determine the strain rate range occurring in typical ship structures.

Laboratory tests of structural steel at the realistic strain rates can then better define steel types for different ship structural applications. Such a definition would help avoid costly overdesigns and still reduce the likelihood of catastrophic failures.

WORK SCOPE

The following tasks outline the scope of the work which should be considered:

1. Review existing shipboard load data which may reveal the range of full-scale strain rates.

2. Collate data on the range of strain rates in accordance with ship types and sea conditions and typical structural areas.

3. Examine and comment on instrumentation used to obtain data.

4. If sufficient data are not available, prepare recommendations to make analytical predictions and carry out tests to obtain the required information with specific emphasis in the following:

a. Number and type of ships to be instrumented.

b. Structural members and specific areas on the ship's hull to be instrumented.

c. Types of instrumentation to be used with suitable alternatives.

d. Specifics on instrumentation, installation, recording, data reduction and costs.

e. Pertinent measurements and instrumentation which will be required, such as sea-state information, ship's speed, roll, pitch, etc.

f. Desirable ship routes, best seasons, general extent and duration of trials to collect meaningful data.

g. Cost estimates to carry out these tests.

MAN-HOURS

1000

PERFORMANCE OF UNDERWATER WELDMENTS SRC Priority 81-2

Long-Range Goal: Fabrication Techniques

OBJECTIVE

The objectives of the proposed research are to gather data on the mechanical properties on wet and wet-backed underwater weldments and to provide guidelines relating these properties to design performance.

BACKGROUND

An American Welding Society committee is drafting a specification for underwater welding. This specification will define several classes of welding; among them are:

- Type A welds are suitable for the same design stresses as their in-air counterparts. Qualification tests include visual, nondestructive inspection (NDI), tensile, bend, macroetching, Charpy impact, and hardness. Hyperbaric dry welding is generally required to achieve this level of performance.

- Type B welds that should be evaluated on fitness for purpose basis. Tensile strength is the same as type A; however, relaxed requirements for visual, NDI, bend, and macroetching apply, since weld properties are usually degraded. This is compatible with state-of-the-art wet welding.

- Type C welds are crack free welds for applications where structural quality is not critical. The designer should satisfy himself that these welds do not

impair the integrity of the structure by creating fracture initiation sites.

In underwater repair situations, providing a dry environment for Type A welds generally increases cost by an order of magnitude over that of Type B wet welds. Naturally, these higher costs are more difficult to justify, and where Type B welds are considered an unknown factor, the choice is often made to go with a non-welded repair of limited capacity (e.g. bolting or grouting), or to do nothing. This is particularly relevant for fixed offshore platforms that cannot be dry-docked for repairs.

A number of questions remain unresolved, particularly those related to the implication of degraded properties that are obtained with Type B wet and wet-backed welds. For example, what level of hardness should be specified (how safe are customer specifications which permit hardnesses of 280-350 Brinell)? Does the reduced ductility allowed for type B welds in a band test imply a reduction in static strength design allowables? What are implications of overmatch and undermatch weld metals? To what extent are fatigue and fracture performance adversely affected by relaxed criteria for weld profile, internal discontinuities (particularly, high levels of porosity); and how should this be reflected in reduced design allowables for Type B welds? What is the significance of the Charpy test or its omission; are other tests more appropriate? Should some kind of

restraint cracking test be considered? When can Type C welds be safely used, and when should they be prohibited?

WORK SCOPE

The following tasks are considered essential in meeting the objective:

1. Synthesize current literature on underwater welding (including the draft AWS specification) and on the relation of weld tests to service performance of marine structures, into a statement of current knowledge in the objective area.

2. Seek out relevant data and review the field performance of actual wet welding repairs which have been made in recent years.

3. Write a report on Tasks 1 and 2 and include a more detailed laboratory test work plan.

4. Conduct a statistically valid series of laboratory tests in which the performance of Type B welds on existing marine steels can be compared to prior data with in-air welds. Tests should simulate the adverse conditions of service experienced by components of marine structures--e.g., tubular joints, stiffener terminations, cruciform welds, and hull repair welds.

5. Formulate specific design guidelines for static strength, and fracture control, which reflect the findings of this research.

<u>MAN-HOURS</u>

2000 First Year

2500 Second Year

LIQUID SLOSH LOADING IN CARGO TANKS SRC Priority 81-3

Long-Range Goal: Loads Criteria

OBJECTIVE

The objective of this study is to determine sloshing loads, for liquids of specific gravities ranging from 0.4 to 2.0 and typical enroute service viscosities, on the boundaries, swash bulkheads and internal framing of partially filled tanks of various proportions.

BACKGROUND

The operations of vessels at sea with partially filled liquid cargo tanks impose dynamic loads on the tank boundaries, swash bulkheads and deep web framing caused by the movement and sloshing of the tank contents. The need for adequate guidance in the design of slack tank structures has been widely recognized. However, the development of such guidance has been delayed by a lack of adequate information on loads due to sloshing. Project SR-1251, "Evaluation of Liquid Dynamics Loads in Slack LNG Cargo Tanks," addressed the problem but concentrated specifically on LNG in tanks with smooth internal surfaces.

A two-year program is proposed to extend these studies to consider the dynamic loading effects of liquids over a range of densities and fill conditions on tanks which may contain internal swash bulkheads or other structural elements.

<u>WORK SCOPE</u>

The following tasks are considered essential to this study:

1. Compile and review data (including results of Project 1251) for the prediction of slosh loads based on analysis, model tests, or full-scale performance.

2. Correlate data on the basis of suitable parameters pertaining to such factors as tank motion, tank shape and size, interior surface construction, liquid properties, such as density, viscosity, and liquid level. Evaluate the usefulness of these data for ship structural design.

3. Devise a program of model testing and analysis to augment existing information. Special attention should be given to scaling effects and combined horizontal and vertical motions.

4. Implement the program of model testing and analysis developed under (c) above.

5. Organize, in a form readily useable in ship design, the dynamic loading data collected and developed into a summary, in terms of ship motions, liquid properties, tank geometries and structural systems, and other pertinent parameters.

<u>MAN-HOURS</u>

First year	-	Tasks (1) - (3)	1000
Second year	-	Tasks (4) - (5)	2500

WAVE SPECTRAL DEVELOPMENT FOR DESIGN PURPOSES SRC Priority 81-4

Long-Range Goal: Loads Criteria

OBJECTIVE

The objective of the project is to develop and present wave spectral families from available hindcast data in a format suitable for design use.

BACKGROUND

The application and availability of wave spectral data to ship and platform design were discussed in SSC-268, Environmental Wave Data for Determining Hull Structural Loadings, and in a SRC report "A Summary of Wave Data Needs and Availability," August 1979. Availability of wave data was treated extensively in SNAME T & R Bulletin 1-37, Maximum Wave Conditions for Design, by Frank Sellars, March 1978. There remains a need for more precise definition of the form of wave data needed for design, keeping in mind the need for standardization of criteria and collapsing the virtually limitless variation of ocean wave forms into something manageable.

Two types of use of wave data in structural design can be identified: Calculation of maximum loads, and calculation of vibration or fatigue loading. Design of modern ocean structures requires examination of both types of loading. Analysis of ship or other structures in waves is also carried out to determine motions, deck immersion, propeller emergence, slamming, resistance augmentation, and

speed reduction. Certain phenomena require nonlinear analysis, which utilizes a time record of waves rather than the spectrum. Ths may be the record from which spectra are derived, or a hypothetical sequence of waves representing a given spectrum. Examples of this type of analysis are stability, mooring, and two-body problems such as ships moored together or to large buoys or towers.

The form of spectral data required differs to some extent with the type of application. Ships or mobile platforms intended to operate over a broad range of ocean areas must be designed structurally to cope with the worst that may be encountered. Ships are designed for unlimited ocean service, or for restricted areas such as coastwise, bays and sounds, rivers, and the Great Lakes. The applicable spectral data will differ according to such geographical limitation.

For purposes of structural design, as well as for estimation of motions, slamming, deck wetness, and resistance increases, a series of realistic spectra is required. These parameters are affected by operating decisions, hence, spectra over a range of intensities are required for meaningful analysis. For this purpose, a dimensionless spectrum is most useful, together with frequency of occurrence data for height-period groups in the ocean areas to be traversed.

Directionality information is vital to a satisfactory understanding of the seaway. Motions,

stresses, deck wetness, and wave forces are affected by the short crestedness of the seas. Wave directionality should be correlated with frequency and wave height. Generally long, low waves (swell) tend to be highly directional, while short, steep waves (especially those generated by circular storms) tend to be widely spread.

An ongoing ABS study indicates that the hindcast wave data by Fleet Numerical Weather Central (FNWC) compares favorably with those measured at Station India in the North Atlantic. The good correlations between the measured and hindcast wave data suggests that wave spectra for design purposes can be derived based on FNWC hindcast data for major U.S. shipping routes.

WORK SCOPE

The following tasks are considered essential in meeting the objective:

1. Identify the specific needs of ocean vehicle designers for wave data.

2. Correlate significant period and significant height with frequency of occurrence for a range of sea states and present results in a suitable tabular or graphic form. Define typical spectra by a suitable multiparameter spectrum, or the sum of two spectra, as appropriate.

3. Correlate directionality with height and period and present results in a suitable tabular or graphic form.

4. Develop a standard representation of a spectrum as a wave record for nonlinear analysis.

Items 2 and 3 must be specific to geographical areas. For use in ship design and analysis, the data could be developed typical of broad areas such as North Atlantic, North Sea, Gulf of Alaska, North-East Pacific, etc.

5. The results should be presented in two volumes, the first to contain the information for design purposes, the second to contain the background and supportive data.

MAN-HOURS

2500

FILLET WELD STRENGTH PARAMETERS FOR SHIPBUILDING

SRC Priority 81-5

Long-Range Goal: Design Methods

OBJECTIVE

The objective of this project is to discover areas in the ship where fillet weld sizes may be safely reduced below present practices and to estimate the saving in construction cost from such reductions.

BACKGROUND

Project SR 1248, "Updating of Fillet Weld Strength Parameters for Shipbuilding," provided information with respect to fillet weld size requirements which included the following:

- A spread exists in the sizes of fillet welds required by the various classification societies for certain locations in the ship.
- The cost of labor and material associated with fillet welding is a significant portion of the cost of the ship's hull structure.
- History shows an insignificant number of fillet weld failure due to insufficient size.
- There is a history of a significant number of cracks in ship structures starting at the toe of fillet welds. However, it appears likely that the occurrence of these cracks is not particularly related to the size of the fillet welds, but rather to problems of poor workmanship.

On the basis of this information, it appears possible that worthwhile savings in ship construction costs may be made by a judicious reduction of the size of fillet welds.

WORK SCOPE

The contractor shall perform the following tasks:

1. Review the work done under project SR 1248.

2. Select two typical designs of ship, such as a tanker and a container ship, and develop fillet weld schedules for them according to American Bureau of Shipping, Det Norske Veritas and Lloyd's Register requirements.

3. Estimate the cost of fillet welding for the three sets of rules and compare this to the cost of the complete hull structure of the two ships, preferably based upon returned cost data.

4. Estimate the cost of fillet welding in the above two ships using the smallest allowable welds from any of the three sets of rules.

5. Select several important weld locations for detailed design analysis - for instance - the connection of stiffeners to plating subjected to hydrostatic head, and the connection of watertight bulkheads to surrounding structure.

6. Calculate, by standard structural engineering procedures, minimum permissible weld sizes for these locations. In addition to the stresses in the weld, consideration should be given to other necessary

requirements such as production, corrosion allowance and weld size to prevent harmful quenching.

7. Compare and comment on these weld sizes in relation to those required by the classfication societies.

8. Estimate the effect on the ships cost that would result from using the rational weld sizes determined in step 5 relative to the costs developed in Task 4.

9. Provide a discussion of the implications for design and production of a more rational approach to fillet weld design and outline additional needed research.

<u>MAN-HOURS</u>

1500

IN-SERVICE STRUCTURAL INSPECTION GUIDELINES — SRC Priority 81-6

Long-Range Goal: Determination of Failure Criteria (Reliability)

OBJECTIVE

The objective of this study is to develop a format for design offices to identify fracture critical components in a ship structure and recommend appropriate inspection techniques for in-service inspection.

BACKGROUND

SSC-272, In-Service Performance of Structural Details by C. R. Jordan and C. S. Cochran (1978) identifies many structural details that have failed in service. Current structural inspection techniques for vessels and marine structures frequently look for the obvious failure or indications of corrosion, etc. Gagings are generally limited to plating. Many structurally critical members are not easily identifiable as such by inspectors in the field, frequently are not readily accessible for inspection and thus, may be slighted or even overlooked.

Guidance for the inspection and location of such details to insure coverage of critical areas should come from the designer, and, conversely, the designer should be aware of the need for accessibility of critical areas for inspection. There is a need for a guide in a standard format that would facilitate inspection, interpretation of inspection reports and feed-back to the designer.

WORK SCOPE

The following tasks are considered essential to meet the objective.

1. Survey current inspection practices, inspection intervals, and inspection points related to structural safety.

2. Survey structural design practices and philosophies along with vessel casualties involving structural failures to identify critical structural elements and key failure modes.

3. Identify areas where current inspection practices and techniques are not commensurate with the anticipated failure modes or potential severity of a failure.

4. Establish criteria by which designers can identify criticality for inspection.

5. Develop a standard format to be used as a basis for in-service inspection.

6. Develop a measure of effectiveness for evaluation of improvements, e.g., a reduction in probability of failure.

MAN-HOURS

1500

MATERIAL REQUIREMENTS FOR HIGH-PERFORMANCE CRAFT

SRC Priority 81-7

Long-Range Goal: Advanced Concepts and Long-Range Planning

OBJECTIVES

The objectives of the study are to determine material data requirements for use of the marine vehicle structural designer and to recommend characterization programs for the selected materials.

BACKGROUND

In the marine industry, there is a developing interest in reducing weight in marine vehicle structures and a corresponding interest in the use of structural materials of higher strength to weight ratio than conventional steels. Interest in their application ranges from conventional displacement hulls, where high strength steels offer benefits of increased payload, which are modest but nevertheless significant over the life of the craft, to airborne and foilborne craft where low structure weight is a key to feasibility. In these latter applications, sophisticated materials and fabrication methods are justified by the large return in both speed and payload capability, relative to the installed power. Both speed and payload are economically beneficial, and speed is especially so for passenger carrying craft.

Materials of interest include high yield strength steels, aluminum alloys, stainless steels, titanium alloys

and, in a more limited way, new material forms such as composites, sandwich construction, etc.

Most of these materials are a carryover from the aerospace industry. In the shipyards, however, more emphasis is placed on weldability, corrosion resistance, and heavier sections and quality control is less rigorous. As a consequence, the extensive material characterization background built up by the aerospace industry, for aircraft and space vehicle applications, is of limited use, and there is a great need of data for the marine application of these materials.

WORK SCOPE

The following tasks are considered necessary to meet the objectives:

1. Contact companies and agencies involved in development of high-performance marine craft to determine applications, resulting requirements imposed on structural materials, materials in use and the rationale behind their selection, and material characterization data required for more effective material application. Include in the consideration high-performance displacement vessels, SWATH ships, air-cushion vehicles, surface-effect ships and hydrofoils.

2. Review available materials; examine strengths and weaknesses relative to requirements, and select two or three materials of potentially wide application for high-performance marine craft. Include in the consideration, as

a minimum, the high yield steels, the high-strength, precipitation-hardened, stainless steels, titanium alloys, aluminum alloys suitable for marine applications, fiberglass and composites.

3. Define characterization data required for the materials of interest. In particular, obtain the point of view of designers who will use the material data, on the required characterization, in addition to the views of material specialists. Define required material test programs, including both parent material and joined and fabricated assemblies. Include in the parameters to be considered the effects of environment, processing and joining, non-destructive inspection, geometric details, etc.

4. Prepare a report to present the results of the study and, in particular, make detailed recommendations for material characterization programs.

MAN-HOURS

1500

FRACTURE CONTROL FOR FIXED OFFSHORE STRUCTURES SRC Priority 81-8

Long-Range Goal: Materials Criteria

OBJECTIVE

The objective of this study is to examine critically the technology and practices that constitute the fracture-control plans used by designers, builders and operators of fixed offshore structures.

BACKGROUND

A fracture-control plan may be defined as a plan by which design options, materials selection, fabrication control, and inspection procedures are integrated into a consistent strategy, with the goal of preventing failure by fracture in service of welded structures.

In the case of fixed offshore platforms, this goal is achieved through the use of redundant structure, the selection of materials with enhanced notch toughness and improved through-thickness properties for critical locations, fabrication quality control, and in-service inspection. To a large extent, these measures fall in the domain of customary practice with some attendant variation from company to company, and from region to region.

For mobile offshore platforms, the American Bureau of Shipping has published Rules for Building and Classing Offshore Mobile Drilling Units (1973).

WORK SCOPE

The following tasks are considered essential in summarizing the fracture-control plans:

1. Review pertinent U.S. and foreign literature.

2. Identify the essential elements and rationale of a fracture-control plan.

3. Identify areas where existing technology would suggest cost-effective improvements in current practice.

4. Identify areas where further research is needed.

MAN-HOURS

1000

COMPUTER-AIDED PROCEDURE FOR SHIP GROUNDING CALCULATIONS — SRC Priority 81-9

Long-Range Goal: Advanced Concept and Long-Range Planning

OBJECTIVE

The objective of the project is to design the logic for computer program which will aid in the assessment of damage, stability, and survivability of grounded vessels.

BACKGROUND

Ship groundings are a significant source of marine environmental damage and account for a large percentage of ship structural failures worldwide. In a grounding, the ship may be damaged so severely that its ability to return to a shipyard, assuming it could be refloated, is questionable. If it is firmly grounded or if the forces of wind, waves, or currents cause it to broach, it may be destroyed or fail with serious damage to the environment and possible loss of life. Current state-of-the-art techniques are sometimes successful if the salvor has time, equipment, and fair weather available as well as a generous portion of luck or providential intercession.

Information is needed to assess the state of damage to the ship, the likelihood of further damage, the possibility and course of action necessary to refloat the vessel, and the effect of various salvage actions on the strength and stability of the vessel. The less severe grounding situations, in which the ship is only locally affected with a large margin of damage stability remaining,

may lend themselves to a computerized approach to analysis. Such a program could be used as an aid to the salvage team to determine the best course of action during an actual casualty and as an after-the-fact analysis tool to determine future design parameters and salvage methods.

WORK SCOPE

The following tasks constitute the major efforts to be accomplished under this project:

1. Review current literature on the subject of grounding and stranding. Reference 1 contains much of the current literature in its list of references.

2. Interview marine salvage organizations with experience in salvaging grounded vessels to determine the state-of-the-art of salvage analysis and their views about needed computer capability.

3. Analyze the factors that affect the ship during transfer from the fully buoyant to the grounded condition and the factors that affect the survivability of the ship.

4. Analyze the factors that affect the damaged ship during transfer from a grounded condition to fully buoyant.

5. Inputs to the program should include but not be limited to the following:

* Hydrostatic properties of the ship including compartments open to the sea.

* Ship's bonjean curves, longitudinal weight distribution, intact stability and deviations from design form characteristics, such as, hogging, sagging, flooded compartments and local damage.

* Flexibility of the ship, including longitudinal bending and local stiffness.

* Sea bottom support characteristics based on the type of sea bottom, i.e., solid rock, gravel, sand, mud.

6. The program should provide outputs that include but are not limited to:

* Evaluation of the stability of the ship.

* Evaluation of the loads, stresses, and deflections of the ship.

* Evaluation of the effect of modifying the weights, buoyancy, damaged compartments, extent of bottom support, and other factors that may not be precisely known or that can be modified to improve survivability of the ship.

7. Prepare a program flow chart.

8. Provide an outline of use based on specific examples of two or three actual tanker casualties.

REFERENCE

1. N. Jones, A Literature Survey on the Collision and Grounding Protection of Ships, SSC-283, 1979.

MAN-HOURS

2000

COMPUTER-AIDED PROCEDURE FOR DRYDOCKING CALCULATIONS SRC Priority 81-10

Long-Range Goal: Design Methods

OBJECTIVE

The objective of this project is to develop a general computer program and prepare a programmer's and user's manual for dry-docking analysis to aid the experienced analyst in calculating individual block loads, primary hull bending loads in docking and stresses in flexible docking floors.

BACKGROUND

Docking ships in either floating drydocks or graving docks can overstress the ship, the docking blocks or the floor of the floating drydock. This is especially true if the ship is damaged or if a unique positioning of the ship on the blocks is required. Variations in the construction of blocks and their arrangement, permissible bow and stern overhang, block failure loads and floating drydock floor strength and stiffness are some of the variables that must be considered by the docking analyst (1--4).

Present methods for calculating the interactive force between the ship and the docking system are time consuming and require an experienced analyst. Therefore, it is desirable to have a computer method to assist the analyst in determining block loads for both rigid and flexible drydock floors.

WORK SCOPE

The following tasks are considered essential in meeting the objective:

1. Review literature on the subject including but not limited to referenced reports.

2. Consult drydocking practitioners regarding their present procedures for calculation and any desired improvements. The interviews are to include both naval and commercial installations and those that operate graving docks, floating one-piece docks, and floating sectional docks.

3. Analyze factors that affect the ship and dock during transfer of the load to the dock.

4. Develop the logic for a program to determine individual docking block loads including consideration of ship form, structural characteristics, permanent hog or sag, weight distribution, block characteristics and arrangement, and docking floor flexibility. Loads should be converted to hull bending moments within the program.

5. Develop a computer program based on the logic developed in task 4.

6. Examples of application of the program should be given; i.e., docking on rigid floor versus docking on flexible floor; and evaluating adequacy of docking blocks, strength of docking floor and local effects on the ship structure.

REFERENCES

1. C.K. Yeh and W.J. Ruby, "A New Method for Computing Keel Block Loads" , Vol. 60, SNAME Transactions, 1952.

2. "Investigation of Pressures on Keel Blocks during Drydocking of CVA41, CVS45 and CVA11," Report 1003, Dvaid Taylor Naval Ship Research and Development Center, (DTNSRDC), April 1956.

3. "Investigation of Loads on Keel Blocks during the Drydocking of CVS45, CVA59 and CVS20," Report 1591, DTNSRDC, February 1962.

4. A.B. Potvin, B.J. Hartz, and G.C. Nickum, Analysis of Stresses in a Floating Drydock due to a Docked Ship", Vol. 77, SNAME Transactions, 1969.

MAN-HOURS

2000

HYDRODYNAMIC DAMPING TESTS SRC Priority 81-11

Long-Range Goal: Response Criteria

OBJECTIVE

The objective of the project is to obtain an improved estimation procedure for, and estimation of, the longitudinal distribution of added mass and damping associated with the principal flexural or "beam" modes of ship hull vibration (primarily vertical).

BACKGROUND

Prediction of vibration levels, fatigue damage accumulation, strain-rates, etc. is strongly dependent on the assumed magnitudes of added mass and energy dissipation. The problem is particularly difficult in the low-frequency range (0.5 to 10.0 Hz) where wave damping and structural deformation are both important (1). At issue is a hydro-elastic problem that has been traditionally treated as a rigid-body problem in determining the hydrodynamic coefficients. Such an approach is expected to be computationally expedient, but not necessarily applicable to structures having a significant amount of large panel flexibility. SSC project SR-1261, "Hull Structural Damping Data," is attempting to develop a set of requirements for experimentally determining the longitudinal distribution of damping coefficients from model and full-scale measurements. It is expected that this project will recommend small-scale model tests to establish the hydrodynamic damping component

and full-scale, forced vibration measurements in an attempt to quantify the structural and cargo damping contributions.

The principal sources of energy dissipation, as suggested above, are:

a) Hydrodynamic damping (radiation and viscous)

b) Structural damping

c) Cargo damping.

The total damping at ship flexural frequencies is small, with the structural component on the order of only 1/2 of 1% critical. Disentangling the external "hydrodynamic" contribution from the internal hydrodynamic (e.g. tank sloshing) and "cargo" related dissipation is not likely to be easy. The damping terms may also differ significantly when excited by random and transient forces as compared with simple sinusoidal excitation. This suggests that valid, full-scale measurements can be obtained, under certain conditions, using ambient excitation rather than forced excitation.

The analysis of both model and full-scale data should be approached in a number of different ways. Hence, one or more of the following procedures should be considered to supplement the methods developed in SSC project SR-1261:

a) Estimate the damping, using spectral analysis technique, in particular the data-adaptive Maximum Entropy Method (MEM) (2,3,4,5)

b) Formulate the model damping response equations as an ARMA model (Auto-Regressive/Moving Average) and compute the damping terms from the model coefficients (3,4).

c) Formulate the analysis procedure as a form of parameter or system identification problem (6).

The current approach to the problem of low-frequency ship-hull vibration is viewed as having three phases. The first phase was the initial experimental designs of SSC project SR-1261. Phase II (this project) will extend the experimental design of Phase I to specific vessels, compute estimates of the added mass and hydrodynamic damping using potential flow theory, and conduct model-scale experiments. Phase III (future project) will involve the measurement and analysis of full-scale data.

WORK SCOPE

The following tasks are considered essential in meeting the objective.

1. Compute the added mass and radiation damping (potential flow) for various frequencies of ship vibration (especially those associated with springing, whipping etc.). Various methods may be appropriate and the investigator should consider such methods as strip theory, the type of hyro-elastic questions of Reference No. 1, and the current work of SSC project SR-1277, "Advanced Method for Ship-Motion and Wave-Load Predictions."

2. Propose a parametric form for the modal viscous damping term and estimate typical values for the model experiments.

3. Perform tests with a flexible model (possibly of simplified cross section), with and without forward speed. Correlate the results with the theoretical hydrodynamic computations.

4. Select a candidate vessel for full-scale measurements for hull vibrations (principally vertical mode), with and without cargo.

5. Formulate the vibration equations and estimate the hydrodynamic terms (added mass and damping). Design a forced-vibration experiment, taking into account the results of SSC project SR-1261. Account should also be taken of the ambient noise inherent in full-scale measurements and the propagation of measurement and computational errors.

6. Outline the data analysis that would be required to analyze any full-scale and model measurements; paying particular attention to the spectral analysis and system identification procedures suggested above.

REFERENCES

1. Webster, W.C., "Computation of the Hydrodynamic Forces Induced by General Vibration of Cylinders," JSR, Vol. 23, No. 1, March 1979.

2. Jenkins and Watts, Spectral Analysis and its Applications. Holden Day, 1968.

3. Campbell, R.B., Ph.D. Thesis, Dept. of Ocean Engineering, MIT, December 1979.

4. Vandiver, J.K. and R.B. Campbell, "Estimation of Natural Frequencies and Damping Ratios of Three Similar Offshore Platforms Using Maximum Entropy Spectral Analysis" ASCE Spring Convention, Boston, April 1979.

5. Ruhl, J.A. and R.M. Berdahl, "Forced Vibration Tests of a Deepwater Platform", O.T.C. Paper 3514, 1979.

6. Armand, J.L. and P. Orsero, "Analytic Identification of Damping in Ship Vibrations from Full-Scale Measurements", RINA Paper No. 14, Dec. 1979

MAN-HOURS

4000 - Two years

ECONOMIC FEASIBILITY OF COPPER-NICKEL CLAD HULLS SRC Priority 81-12

Long-Range Goal: Advanced Concepts and Long-Range Planning

OBJECTIVE

The objective of this study is to conduct an up-to-date, economic analysis of the feasibility of using Cu-Ni cladding on the hulls of large containerships and tankers.

BACKGROUND

Copper-nickel hulls and Cu-Ni clad steel hulls have been reported to resist biofouling and corrosion in ocean going ships (1, 2). Expected benefits are substantial fuel and maintenance savings, especially for warm water operations.

Service experience has been limited to relatively small shrimp boats (COPPER MARINER and COPPER MARINER II) (3) (GREAT LAND and WESTWARD VENTURE) (4). Data from these ships and other research programs have shown that Cu-Ni clad hull steels may indeed provide significant fuel and maintenance savings as well as more operational time.

Economic studies of Cu-Ni-clad steels conducted in the past few years have been based on very limited data (5). It is expected that a more valid economic analysis could now be made using the new data and directed toward larger containerships and tankers. The recently completed life-cycle cost analysis (6) is directed at such an application.

WORK SCOPE

The following tasks are considered essential to the study:

1) Prepare a review evaluating all literature and experience pertinent to the use of Cu-Ni clad hull plates.

2) Using up-to-date costs and fabrication techniques, conduct an economic feasibility analysis (following the SSC-289 method), comparing Cu-Ni clad steels to standard steel hulls in large containerships and tankers. Consider various Cu-Ni alloys, their respective properties and the ship routes to be used (e.g. cold water vs. warm water routes).

3. Summarize and rank areas (both technical and non-technical) that need additional study to refine the economic analysis or establish production feasibility.

REFERENCES

1. Proceedings of the Sixth International Ship Structures Congress, 1976.

2. Proceedings of the Seventh International Ship Structures Congress, 1979.

3. J.L. Manzolillo, et. al., "CA-706 Copper-Nickel Alloy Hulls: The Copper Mariner's Experience and Economics," SNAME Trans., Vol. 84, 1976.

4. E. Schorsch, et. al., "Hull Experiments on 24 - Knot RO/RO Vessels Directed Toward Fuel-Saving Application of Copper-Nickel," SNAME Trans., Vol. 86, 1978, pp. 254-276.

5. E. Numata, Potential Market and Effect on Operational Economics of Copper-Nickel Clad Steels for Ship Hulls, Davidson Laboratory Report SIT-DL-76-1913, September, 1976.

6. C.R. Jordan, et al., A Method for Economic Trade-Offs of Alternate Ship Structural Materials, SSC-289, 1979.

MAN-HOURS

1000

STRUCTURAL MODELING GUIDE FOR NUMERICAL ANALYSIS SRC Priority 81-13

Long-Range Goal: Design Methods

OBJECTIVE

The objective of this project is to produce a structural modeling guide for numerical analysis to improve efficiency, accuracy and cost effectiveness of solutions to complex ship structural problems.

BACKGROUND

Development of a mathematical model is one of the most important and time-consuming elements in numerical analysis. The model must not only perform as the structure does and be compatible with the computer program selected for analysis, it should be no more complex than necessary to obtain the desired results.

Guidance to the analyst in selecting the proper model to efficiently utilize the major computer programs in analysis of ship-type structure problems will help the naval architect to be more cost effective and timely. Presently, the analyst must consider:

- The time and money available for analysis; the problem size limited by available program or computer systems; and the simplest type of model (two- or three dimensional, truss, gridwork, framework, etc.) possible to do the job. Special features available with some computer systems such as pre- and post processors, and plotting (or graphics) packages, can significantly influence the cost.

- The type of analysis also influences the modeling by virtue of differing convergence rates for different types of analyses; e.g., a static, linear, displacement analysis is cheap while other types of analyses. (involving buckling, nonlinearities, dynamics) are expensive and thus impose much more severe practical limitations on problem size.

- The types of outputs (stresses, displacements, frequencies, etc.) also influence the modeling because of differing element convergence properties, i.e., stresses frequently require a finer mesh than do displacements for a given degree of accuracy.

- The global behavior of the structure or the behavior in a localized area influences the extent of the structure modeled as well as the distribution or nodal densities. Obviously, the highest nodal densities should occur in the regions of particular interest.

- The behavior of elements on element types in different situations can range from poor to excellent and thus a knowledge of their characteristics is necessary. More sophisticated elements are generally cheaper to use because fewer are required.

- Frequently, only membrane or bending behavior is of importance in a given problem. In such situations the degrees of freedom associated with the other type of behavior may often be eliminated, thus substantially reducing the problem size. This requires, of course, a

solid understanding of the nature of the behavior of the structure in question.

This project is not to be an evaluation of various programs; but rather to develop a guide to aid in selecting the most cost-effective program to achieve a desired accuracy.

WORK SCOPE

The following tasks are considered essential in meeting the objective:

1. Develop a matrix of ship structural problem types (dynamic - static, uniform - concentrated load, stress - deflection, etc.) related to the types of elements and programs with some assessment of cost versus accuracy.

2. Develop a step-by-step procedure for examining a problem, developing a model, and selecting a suitable program.

3. Select a ship type problem from the matrix and demonstrate how the procedure in Task 2 would be applied.

MAN-HOURS

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REVIEW OF ACTIVE AND PENDING PROJECTS

This section of the report covers current projects funded with fiscal 1979 (or earlier) funds, others that have been continued with fiscal 1980 funds, and those which are anticipated to be supported with fiscal 1980 funds. These projects, listed in Table III, constitute the current program. The majority of projects are for one-year's duration; multiyear projects are funded incrementally on an annual basis.

Project descriptions, including the SR project number and title, the name of the principal investigator and his organization, where these have been determined, and the activation date and funding, where applicable, are provided. The appropriate SSC Long-Range Goal is also noted, and a very brief statement of the objective of each project is given. These are followed by a short description of the present status of the project.

This format does not permit a detailed or comprehensive description of individual projects; however, each project included will normally result in one or more SSC reports.

TABLE III -- REVIEW OF ACTIVE AND PENDING PROJECTS

PROJECT NO: SR-1238
PROJECT TITLE: FRACTURE TOUGHNESS CHARACTERIZATION OF SHIP STEEL WELDMENTS
INVESTIGATOR: Dr. A. K. Shoemaker
CONTRACTOR: U.S. Steel Corporation, Monroeville, PA
ACTIVATION DATE: January 28, 1977
CONTRACT FUNDING: $62,212
SSC LONG-RANGE GOAL: Materials Criteria
CONTRACT NUMBER: DOT-CG-63116-A

OBJECTIVE

The objective is to determine the relevance of the Charpy V-notch energy criteria currently employed in assessing the behavior of steel weldments.

STATUS

Fatigue-crack-initiation sites, fatigue-crack path, and fatigue strength at 10^6 cycles were determined for weldments both with and without full weld reinforcement and with and without the original mill plate surface. Using fracture mechanics procedures, service behavior under severe operating conditions, as estimated from results of the surface cracked weldment test, was compared with behavior predicted from various fracture-toughness tests and with behavior expected for weldments meeting the toughness requirements of the current ABS Charpy criterion and proposed NDT-DT criterion of Rolfe.

A draft final report has been reviewed and a revised draft is underway.

PROJECT NO:	SR-1245
PROJECT TITLE:	REDUCTION OF SL-7 SCRATCH-GAGE DATA
INVESTIGATOR:	Mr. R. F. Brodrick
CONTRACTOR:	Teledyne Engineering Services, Waltham, MA
ACTIVATION DATE:	March 1977
CONTRACT FUNDING:	$88,511
SSC LONG-RANGE GOAL:	Response Criteria
CONTRACT NUMBER:	DOT-CG-61712-A & 844331-A

OBJECTIVE

The objective is to obtain and reduce two additional years of scratch-gage records from eight SL-7 containerships to usable form and to compare these data with electrical strain-gage data obtained aboard the SL-7 SEA-LAND McLEAN.

STATUS

One additional year of data has been collected and is being reduced. Preliminary comparisons of the first few voyages of the McLEAN electrical strain-gage data and scratch-gage data have been started.

The cooperation of ship personnel continues at a high level.

PROJECT NO: SR-1254
PROJECT TITLE: FATIGUE CONSIDERATIONS IN VIEW OF MEASURED LOAD SPECTRA
INVESTIGATOR: Mr. R.F. Brodrick
CONTRACTOR: Teledyne Engineering Services, Waltham, MA
ACTIVATION DATE: June 21, 1978
CONTRACT FUNDING: $58,582
SSC LONG-RANGE GOAL: Materials Criteria
CONTRACT NUMBER: DOT-CG-80359-A

OBJECTIVE

The objective of this study is to assess the influence of the extent of retardation effects under fatigue loading spectra.

STATUS

A detailed method for selecting short-term stress histories for characterizing ship structure fatigue experience and preliminary results from an experimental program have been obtained. Additional effort and funds will be required to complete the project.

PROJECT NO: SR-1256
PROJECT TITLE: INVESTIGATION OF STEELS FOR IMPROVED WELDABILITY IN SHIP CONSTRUCTION
INVESTIGATOR: Dr. B.G. Reisdorf
CONTRACTOR: U.S. Steel Corporation, Monroeville, PA
ACTIVATION DATE: September 29, 1978
CONTRACT FUNDING: $204,796
SSC LONG-RANGE GOAL: Fabrication Techniques
CONTRACT NUMBER: DOT-CG-80588-A

OBJECTIVE

The objective of this three-year study is to select the optimum materials and welding parameters to improve resistance to degradation of the heat-affected-zone (HAZ) properties in weldments made with high-deposition rate processes.

STATUS

Two production steels and twenty 500-pound laboratory heats of steels of varying chemical compositions reflecting low carbon and sulfur content, silicon-aluminum deoxidation practice, globular sulfides, fine titanium nitrides, and treatments with rare earth metals, boron and calcium are being prepared for HAZ testing. Gleeble Charpy V-notch specimens have been selected to identify those compositions that show promise of developing good HAZ toughness. Weldments will then be made for the selected compositions and for the two reference steels.

PROJECT NO: SR-1257
PROJECT TITLE: FATIGUE CHARACTERIZATION OF FABRICATED SHIP DETAILS
INVESTIGATOR: Prof. W.H. Munse
CONTRACTOR: University of Illinois, Urbana, IL
ACTIVATION DATE: November 30, 1978
CONTRACT FUNDING: $95,016
SSC LONG-RANGE GOAL: Materials Criteria
CONTRACT NUMBER: DOT-CG-823899-A

OBJECTIVE

The objective of this two-year study is to classify ship details in terms of their behavior and useful life under cyclic-loading conditions.

STATUS

A classification procedure has been proposed and demonstrated that involves determining the maximum allowable fatique stress for each selected detail, based on the anticipated total number of stress cycles, the loading type and desired reliability, and the fatique resistance data. These data will be tabulated for various details in terms of mean resistance and coefficient at variation.

The second year's effort will be devoted to conducting experimental studies on selected details to verify the accuracy of the above classification procedure and to classify the behavior and useful life of fabricated ship details whose fatique behaviors are not known.

PROJECT NO: SR-1259
PROJECT TITLE: A LONG-RANGE RESEARCH PROGRAM IN SHIP STRUCTURES
INVESTIGATOR: Mr. J.J. Hopkinson
CONTRACTOR: Gibbs & Cox, Inc., Arlington, VA
ACTIVATION DATE: January 31, 1979
CONTRACT FUNDING: $213,740
SSC LONG-RANGE GOAL: Advanced Concepts and Long-Range Planning
CONTRACT NUMBER: DOT-CG-80371-A

OBJECTIVE

The objective of this two-year study is to develop a marine structures planning document directed toward, but not limited to, the technical goals and charter of the Ship Structure Committee, and to forecast the research and development needs, based on a system of priorities, for the next 20 years.

STATUS

The first plenary sessions to develop the long-range research plan is scheduled for June 24, 25, 26, 1980 at the U.S. Naval Academy. Working papers for each of the SSC long-range goals have been prepared to assist in developing candidate research projects. A method for assessing benefits and establishing priorities to these projects is being refined.

PROJECT NO: SR-1261
PROJECT TITLE: HULL STRUCTURAL DAMPING DATA
INVESTIGATOR: Mr. T.P. Carroll
CONTRACTOR: Carroll Associates, Bethesda, MD
ACTIVATION DATE: February 1979
CONTRACT FUNDING: $21,733
SSC LONG-RANGE GOAL: Design Methods
CONTRACT NUMBER: DOT-CG-824267-A

OBJECTIVE

The objective of this study is to collect and evaluate structural damping data applicable to ship vibration analysis, and to recommend an experimental program, model or full scale, to expand and verify the design data.

STATUS

The available damping data show a wide range of scatter. Most damping experiments have been deficient in providing either the total damping, or have not considered the distribution of damping along the ship's hull, or have generated weak responses from the shaker equipment, or have neglected effects of forward speed. Factors now under consideration are the separation of hydrodynamic from structural damping, justification for using the hull girder as a non-uniform free-free beam, appropriate calculations from deflection to moment to shear to load distrubtions to added mass, damping and springing forces, the role of elastic deformation of large panels and side effects of full-scale measurements in shallow water.

PROJECT NO: SR-1263
PROJECT TITLE: SHIP STRUCTURAL DESIGN CONCEPTS - PART II
INVESTIGATOR: Dr. J.H. Evans
CONTRACTOR: J.H. Evans, Lexington, MA
ACTIVATION DATE: March 1, 1978
CONTRACT FUNDING: $25,000
SSC LONG-RANGE GOAL: Design Methods
CONTRACT NUMBER: DOT-CG-80358-A

OBJECTIVE

The objective of this two-year study is to prepare a supplementary monograph to the Ship Structural Design Concepts published in 1974.

STATUS

The revised title is "Second-Cycle Ship Structural Design Concepts" and chapter titles have been changed to 1. Shear Stresses Due to Bending, 2. Torsion, 3. Hull Deckhouse Interaction, 4. Principal Stresses (and Extent of Unreduced Scantlings), 6. Hull Girder Deflections and Stiffness, 6. Full-Scale Longitudinal Strength Experiments, and 7. Preliminary Choice of Framing Systems and Hull Girder Proportions (and Hull Synthesis in the Presence of Bending plus Shear). A panel of the SNAME Hull Structure Committee is reviewing the chapters for the SSC.

PROJECT NO:	SR-1266
PROJECT TITLE:	CRITERIA FOR HULL/MACHINERY RIGIDITY COMPATIBILITY
INVESTIGATOR:	Prof. J.G. deOliveria
CONTRACTOR:	Massachusetts Institute of Technology, Cambridge, MA
ACTIVATION DATE:	September 24, 1979
CONTRACT FUNDING:	$50,000
SSC LONG-RANGE GOAL:	Response Criteria
CONTRACT NUMBER:	DOT-CG-912506-A

OBJECTIVE

The objective of this study is to develop criteria for compatability in rigidity of hull and main-propulsion machinery.

STATUS

A survey of major U.S. and foreign machinery manufacturers and shipyards has been completed. Reviews of the design of main engine, gear and thrust bearing support structures, and of available analytical procedures for determining the coupled response of hull and machinery are underway. Identification of criteria defining structural rigidity of machinery support systems will soon commence.

PROJECT NO: SR-1267
PROJECT TITLE: ICE STRENGTHENING CRITERIA FOR SHIPS
INVESTIGATOR: Dr. R.P. Voelker
CONTRACTOR: ARCTEC, Incorporated, Columbia, MD
ACTIVATION DATE: August 20, 1979
CONTRACT FUNDING: $56,223
SSC LONG-RANGE GOAL: Loads Criteria
CONTRACT NUMBER: DOT-CG-904937-A

OBJECTIVE

The objective of this study is to develop a basis for rational selection of ice strengthening criteria for vessels.

STATUS

Identifying and comparing current materials and fabrication techniques for ice-strengthened vessels and defining ice characteristics and their distribution for geographic areas of interest are being completed. Because most classification societies have based their ice-strengthening criteria on work by B.M. Johansson, a comparison has shown that only minor differences prevail. The review of existing ice-strengthened vessels performances has not been too successful. The remaining project effort is to identify deficiences in the current ice-strengthening selection procedure, develop a rational selection basis, and recommend any future research in this area.

PROJECT NO: SR-1268
PROJECT TITLE: EVALUATION OF SL-7 SCRATCH-GAGE DATA
INVESTIGATOR: Dr. P.R. Van Mater, Jr.
CONTRACTOR: Giannotti and Associates, Inc., Annapolis, MD
ACTIVATION DATE: September 26, 1979
CONTRACT FUNDING: $21,097
SSC LONG-RANGE GOAL: Response Criteria
CONTRACT NUMBER: DOT-CG-920932-A

OBJECTIVE

The objective of this study is to establish a measure for judging when sufficient scratch-gage data have been obtained so that the gages can be removed for placement aboard other ships.

STATUS

All raw and processed data from Project SR-1245 will be analyzed to validate the data and evaluate experimental discrepancies. The data will then be applied to long-term (life-cycle) and short-term extreme value predictions. Based on these results, statistical and probablistic techniques will be used to determine the adequacy of the data sample, quantity of data and when and how many scratch gages can or should be placed on other ships.

PROJECT NO:	SR-1269
PROJECT TITLE:	INTERNAL CORROSION AND CORROSION CONTROL ALTERNATIVES
INVESTIGATOR:	Mr. C.R. Jordan
CONTRACTOR:	Newport News Shipbuilding and Drydock Company, Newport News, VA
ACTIVATION DATE:	January 14, 1980
CONTRACT FUNDING:	$50,850
SSC LONG-RANGE GOAL:	Materials Criteria
CONTRACT NUMBER:	DOT-CG-912913-A

OBJECTIVE

The objective of this project is to develop a method for making sensitivity studies of the relative life-cycle costs of corrosion control techniques--including combinations of increased scantlings, full or partial coatings, and anodes--to protect internal surfaces of ballast and cargo tanks in steel tankers.

STATUS

Data are being collected on repair and construction costs in domestic and foreign shipyards as well as on performance of corrosion control systems. Plans are being made to develop a procedure that will account for life-cycle costs and evaluate performance and sensitivity of corrosion control systems.

PROJECT NO: SR-1270
PROJECT TITLE: SURVEY OF EXPERIENCE USING REINFORCED CONCRETE IN FLOATING MARINE STRUCTURES
INVESTIGATOR: Dr. O.H. Burnside
CONTRACTOR: Southwest Research Institute, San Antonio, TX
ACTIVATION DATE: November 26, 1979
CONTRACT FUNDING: $29,108
SSC LONG-RANGE GOAL: Advanced Concepts and Long-Range Planning
CONTRACT NUMBER: DOT-CG-919837-A

OBJECTIVE

The objective of this project is to assess the state-of-the-art for reinforced concrete, including prestressed and conventionally reinforced concrete, applicable to floating marine structures.

STATUS

Efforts have been started to gather, tabulate and analyze design and material information on reinforced concrete so that gaps in current technology can be easily recognized. This will in turn lead to identification of areas for future research from which a schedule of research studies will be formulated.

PROJECT NO:	SR-1271
PROJECT TITLE:	PRESSURE DISTRIBUTION MODEL TESTS IN WAVES
INVESTIGATOR:	Prof. A.W. Troesch
CONTRACTOR:	Univ. of Michigan, Ann Arbor, MI
ACTIVATION DATE:	September 25, 1979
CONTRACT FUNDING:	$60,063
SSC LONG-RANGE GOAL:	Response Criteria
CONTRACT NUMBER:	DOT-CG-913367-A

OBJECTIVE

The objective of the project is to measure model-test hull surface pressures and compare them with calculated pressures.

STATUS

Arrangements are being made to instrument two ship models at ten stations, with three measurements per station--at the keel, near the bilge, and close to the free surface. In any given test, the profiles of the incident wave, the heave and pitch of the model, and six pressure measurements will be recorded and digitized. The results will be compared with the American Bureau of Shipping computed results and with those predicted by theory.

PROJECT NO:	SR-1272
PROJECT TITLE:	COMPUTER-AIDED PROCEDURE FOR SHIP GROUNDING CALCULATIONS
INVESTIGATOR:	Unknown
CONTRACTOR:	Unknown
ACTIVATION DATE:	Unknown
CONTRACT FUNDING:	2000 Man-hours
SSC LONG-RANGE GOAL:	Advanced Concepts and Long-Range Planning
CONTRACT NUMBER:	To be assigned

OBJECTIVE

The objective of this project is to develop a general purpose computer program for ship grounding analysis.

STATUS

This project was postponed. It is now being reconsidered in the list of 1981 fiscal year projects as priority 81-9.

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REVIEW AND RECOMMENDATIONS FOR THE INTERAGENCY SHIP STRUCTURE C--ETC(U)
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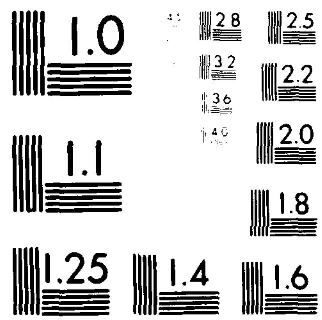

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

PROJECT NO:	SR-1273
PROJECT TITLE:	COMPUTER-AIDED PROCEDURE FOR DRYDOCKING CALCULATIONS
INVESTIGATOR:	Unknown
CONTRACTOR:	Unknown
ACTIVATION DATE:	Unknown
CONTRACT FUNDING:	2000 Man-hours
SSC LONG-RANGE GOAL:	Design Methods
CONTRACT NUMBER:	To be assigned

OBJECTIVE

The objective of the project is to develop a computer program to calculate individual drydock block loads, primary hull-bending loads upon drydocking and the stresses in the pontoon deck of the floating drydock.

STATUS

This project was postponed. It is now being reconsidered in the list of 1981 fiscal year projects as priority 81-10.

PROJECT NO:	SR-1274
PROJECT TITLE:	COMPUTER-AIDED, PRELIMINARY SHIP STRUCTURAL DESIGN
INVESTIGATOR:	Dr. A. E. Mansour
CONTRACTOR:	Mansour Engineering, Inc., Berkeley, CA
ACTIVATION DATE:	September 18, 1979
CONTRACT FUNDING:	$23,560
SSC LONG-RANGE GOAL:	Design Methods
CONTRACT NUMBER:	DOT-CG-919802-A

OBJECTIVE

The objective of this project is to assess the state-of-the-art of computer-aided design systems in both ship and non-ship areas for use in preliminary ship structural design.

STATUS

A literature survey of computer-aided procedures applied to marine structures shows more analysis oriented than design oriented procedures being reported. The diversity and amount of information in the non-marine area has required more effort and a more selective approach, which has produced the desirable and mandatory criteria a computer-aided, preliminary ship structural design program should meet. Evaluating these reports and developing a plan of action that describes the goals, requirements and function of the computer-aided preliminary ship structural design program will complete the project work.

PROJECT NO:	SR-1275
PROJECT TITLE:	FULL-SCALE PRESSURE DISTRIBUTION MEASUREMENTS OF M/V S.J. CORT
INVESTIGATOR:	Mr. A.L. Dinsenbacher
CONTRACTOR:	David Taylor Naval Ship Research and Development Center, Carderock, MD
ACTIVATION DATE:	December 19, 1978
CONTRACT FUNDING:	$76,700
SSC LONG-RANGE GOAL:	Response Criteria
CONTRACT NUMBER:	N6519779PO90714

OBJECTIVE

The objective is to measure full-scale pressure distributions to validate pressure prediction analysis methods.

STATUS

The original fifteen pressure gages installed on the M/V S.J. CORT's hull plating were destroyed by ice compacting so the 1979 spring trial data were not obtained. These pressure gages were replaced in time to obtain the 1979 fall data, which are now being analyzed. A second year of data collection is being considered.

PROJECT NO:	SR-1276
PROJECT TITLE:	LONG-TERM CORROSION FATIGUE OF WELDED MARINE STEELS
INVESTIGATOR:	Unknown
CONTRACTOR:	Unknown
ACTIVATION DATE:	Unknown
CONTRACT FUNDING:	2000 man-hours each for two years
SCC LONG-RANGE GOAL:	Materials Criteria
CONTRACT NUMBER:	DTCG-23-80-R-01757

OBJECTIVE

The objective of the proposed research is to define and evaluate currently available technology for assessing the long-life corrosion fatigue behavior of welded joints in sea water; and to develop a plan for long-term future efforts, if required.

STATUS

A request for proposals has been issued.

PROJECT NO:	SR-1277
PROJECT TITLE:	ADVANCED METHOD FOR SHIP-MOTION AND WAVE-LOAD PREDICTIONS
INVESTIGATOR:	Unknown
CONTRACTOR:	Unknown
ACTIVATION DATE:	Unknown
CONTRACT FUNDING:	1500 man-hours first year, 2500 man-hours second year
SSC LONG-RANGE GOAL:	Loads Criteria
CONTRACT NUMBER:	To be assigned

OBJECTIVE

The objective of the study is to develop a method and appropriate computer program for predicting ship motions and distributed wave loads, taking into account the hull form shape above and below the still waterline, including the three-dimensional hydrodynamic coefficients.

STATUS

A proposal request has been prepared.

PROJECT NO:	SR-1278
PROJECT TITLE:	STEELS FOR MARINE STRUCTURES IN ARCTIC ENVIRONMENTS
INVESTIGATOR:	Unknown
CONTRACTOR:	Unknown
ACTIVATION DATE:	Unknown
CONTRACT FUNDING:	1500 man-hours
SSC LONG-RANGE GOAL:	Materials Criteria
CONTRACT NUMBER:	DTCG-23-80-R-20003

OBJECTIVE

The objective of the study is to evaluate reserch reports and other literature on material selection, fabrication techniques, and material reliablity on non-marine cold-weather applications to determine the usefulness of these materials and techiques for marine structures in an Arctic environment.

STATUS

A request for proposals has been issued.

PROJECT NO:	SR-1279
PROJECT TITLE:	SL-7 PROGRAM SUMMARY, CONCLUSIONS AND RECOMMENDATIONS
INVESTIGATOR:	Unknown
CONTRACTOR:	Unknown
ACTIVATION DATE:	Unknown
CONTRACT FUNDING:	1000 man-hours
SSC LONG-RANGE GOAL:	Response Criteria
CONTRACT NUMBER:	DTCG-23-80-R-02399

OBJECTIVE

The objective of the study is to review and evaluate the plans, procedures, results and accomplishments of the SL-7 program.

STATUS

A request for proposals has been issued.

PROJECT NO:	SR-1280
PROJECT TITLE:	ANALYSIS AND ASSESSMENT OF MAJOR UNCERTAINTIES IN SHIP HULL DESIGN
INVESTIGATOR:	Unknown
CONTRACTOR:	Unknown
ACTIVATION DATE:	Unknown
CONTRACT FUNDING:	1000 man-hours
SSC LONG-RANGE GOAL:	Determination of Failure Criteria (Reliability)
CONTRACT NUMBER:	To be assigned

OBJECTIVE

The objective of the study is to identify the major sources of uncertainties underlying the design of ship hull structures.

STATUS

A proposal request has been prepared.

PROJECT NO: SR-1281
PROJECT TITLE: SHIP STRUCTURES LOADING IN EXTREME WAVES
INVESTIGATOR: Unknown
CONTRACTOR: Unknown
ACTIVATION DATE: Unknown
CONTRACT FUNDING: 1000 man-hours
SSC LONG-RANGE GOAL: Loads Criteria
CONTRACT NUMBER: To be assigned

OBJECTIVE

The objective of the study is to examine the probability of a ship encountering some kinds of extreme waves and to understand the significance of this in ship structural design.

STATUS

A proposal request has been prepared.

PROJECT NO:	SR-1282
PROJECT TITLE:	IN-SERVICE STILL-WATER BENDING MOMENT DETERMINATION
INVESTIGATOR:	Unknown
CONTRACTOR:	Unknown
ACTIVATION DATE:	Unknown
CONTRACT FUNDING:	1000 man-hours
SSC LONG-RANGE GOAL:	Loads Criteria
CONTRACT NUMBER:	To be assigned

OBJECTIVE

The objective of the study is to develop a plan to obtain in-service still-water loading data.

STATUS

A proposal request has been prepared.

REVIEW OF COMPLETED PROJECTS

The projects completed since the last annual report are listed below. Project descriptions, similar to those for the active program, follow. Reports from these projects have either been published or are presently in the publication process and the final SSC reports can be expected in the near future.

- SR-1241, "Longitudinal Strength Criteria Based on Statistical Data Analysis"
- SR-1251, "Evaluation of Liquid Dynamic Loads in Slack Cargo Tanks"
- SR-1255, "Nondestructive Inspecton of Heavy Section Castings, Forgings, and Weldments"
- SR-1258, "Structural Details Failure Survey Continuation"
- SR-1262, "Ultimate Strength of Ship Hull Girder"
- SR-1265, "Evaluation of Fracture Criteria for Ship Steels and Weldments"

PROJECT NO:	SR-1241
PROJECT TITLE:	LONGITUDINAL STRENGTH CRITERIA BASED ON STATISTICAL DATA ANALYSIS
INVESTIGATOR:	Mr. N. S. Basar
CONTRACTOR:	M. Rosenblatt & Son, Inc., New York, NY
ACTIVATION DATE:	September 30, 1976
CONTRACT FUNDING:	$19,064
SSC LONG-RANGE GOAL:	Design Methods
CONTRACT NUMBER:	DOT-CG-61908-A

OBJECTIVE

The objective of this study is to develop a computer program for a method for analysis of uncertainties associated with ship hull strength due to mill practices, methods of sampling, variations in material properties and scantlings, time-dependent effects, etc. with expressions for margins of safety and structural reliability.

RESULTS

A computer algorithm was developed to analyze any number of ships for any number of modes of failure. Each ship and mode of failure requires its own data set, however. There is also an option to input the strength coefficient of variation (COV) or have it computed by inputing the uncertainty COV's and computing the strength COV by subroutines for that purpose. Although the only such subroutine presently included in the program is that for ductile yielding of the hull girder in vertical bending, the program has been structured to allow for additional subroutines to be added for other modes of failure.

PROJECT NO: SR-1251
PROJECT TITLE: EVALUATION OF LIQUID DYNAMIC LOADS IN SLACK LNG CARGO TANKS
INVESTIGATOR: Dr. R.L. Bass
CONTRACTOR: Southwest Research Institute, San Antonio, TX
ACTIVATION DATE: September 16, 1977
CONTRACT FUNDING: $72,159
SSC LONG-RANGE GOAL: Loads Criteria
CONTRACT NUMBER: DOT-CG-71374-A

OBJECTIVE

The objective of this study is to survey, test, analyze, and develop liquid dynamic load criteria in slack LNG cargo tanks.

RESULTS

A significant amount of scale-model sloshing data for both prismatic and spherical tanks and covering a wide range of fill depths, excitation frequencies and amplitudes, tank wall pressure measurement locations and total force measurements are now available in a common format to provide design pressure and force coefficients.

Design methods are also available for independent pressure and gravity tanks and membrane and semi-membrane tanks. The design sequence proceeds from comparing ship periods to predicted resonant slosh periods to establishing loads based on load coefficients to designing structures by specific delineated methods which vary with tank type.

PROJECT NO:	SR-1255
PROJECT TITLE:	NONDESTRUCTIVE INSPECTION OF HEAVY SECTION CASTINGS, FORGINGS, AND WELDMENTS
INVESTIGATOR:	Mr. E.L. Criscuolo
CONTRACTOR:	Naval Surface Weapons Center, White Oak, MD
ACTIVATION DATE:	June 1, 1977
CONTRACT FUNDING:	$20,000
SSC LONG-RANGE GOAL:	Fabrication Techniques
CONTRACT NUMBER:	NAVY Z 70099-6-71375

OBJECTIVE

The objective of this study is to survey representative nondestructive inspection methods for ship castings, forgings, and weldments, and identify existing acceptance standards.

RESULTS

Code bodies, notably ASTM, have produced procedural guides, standard methods, and recommended practices that can be used to assure proper inspection for various methods of nondestructive testing. These guides and practice in private industry have been reviewed for their applicability to quality control of heavy steel castings, forgings, and weldments. While they do not set forth acceptance criteria, they do define levels of quality and describe the parameters generally agreed to be of significance.

PROJECT NO:	SR-1258
PROJECT TITLE:	STRUCTURAL DETAILS FAILURE SURVEY CONTINUATION
INVESTIGATOR:	Mr. C.R. Jordan
CONTRACTOR:	Newport News Shipbuilding and Dry Dock Company, Newport News, VA
ACTIVATION DATE:	December 6, 1977
CONTRACT FUNDING:	$49,761
SSC LONG-RANGE GOAL:	Fabrication Techniques
CONTRACT NUMBER:	DOT-CG-75172-A

OBJECTIVE

The objective of this study is to evaluate the effectiveness of structural details by examining several details in selected ships undergoing repairs or periodic surveys.

RESULTS

The midship cargo areas of twelve bulk carriers, twelve containerships, and twelve general cargo ships were surveyed during a fourteen month period and produced eighty-one new detail variations for the twelve existing structural detail families. This increases the number of configurations for an overall eighty-six ship survey to 634 distinct detail variations.

A total of 117,374 details were observed with a total of 3,555 failures, yielding a failure rate of 3.03% for the second survey. In the first fifty-ship survey, the 3,301 failures of the 490,210 details observed, resulted in a failure rate of 0.67%. By combining the data in the two surveys, the results show 6,856 failures for 607,584 observed details or a failure rate of 1.13%.

PROJECT NO: SR-1262
PROJECT TITLE: ULTIMATE STRENGTH OF SHIP HULL GIRDER
INVESTIGATOR: Dr. A. E. Mansour
CONTRACTOR: Mansour Engineering, Inc., Berkeley, CA
ACTIVATION DATE: May 1, 1978
CONTRACT FUNDING: $37,080
SSC LONG-RANGE GOAL: Design Methods
CONTRACT NUMBER: DOT-CG-74755-A

OBJECTIVE

The objective of this study is to develop a procedure to determine the load-deformation characteristics and ultimate strength of a ship hull girder under various combinations of vertical, lateral, and torsional loads.

RESULTS

Limiting conditions were analyzed, with buckling and instability of the hull stiffened plates, fully plastic yield moments, and shakedown moments being further developed into a procedure for estimating the ultimate capacity of the hull. New interaction relations for the ultimate strength of ships subjected to combined moments were developed in this study. The fracture (fatigue and brittle) modes of failure were not included. The procedure was then applied to a 200,000 ton displacement tanker.

Lack of adequate formulations in certain areas were pointed out particularly when the collapse mode involved coupling among several mechanisms of failure.

PROJECT NO:	SR-1265
PROJECT TITLE:	EVALUATION OF FRACTURE CRITERIA FOR SHIP STEELS AND WELDMENTS
INVESTIGATOR:	Prof. A.W. Pense
CONTRACTOR:	Prof. A.W. Pense, Bethlehem, PA
ACTIVATION DATE:	April 4, 1978
CONTRACT FUNDING:	$6,800 from American Iron and Steel Institute
SSC LONG-RANGE GOAL:	Materials Criteria
CONTRACT NUMBER:	AISI Grant

OBJECTIVE

The objective of this study is to prepare a state-of-the-art interpretative report on the correlation of fracture toughness in ship steels and weldments to proposed criteria for adequate resistance to fracture in service.

RESULTS

Available data indicate that Rolfe's proposed fracture-toughness guidelines are conservative. Available testing methods do not produce an intermediate loading rate between the static and dynamic rates presently being used. Available full-scale shipboard strain-rate data are too few to assign proper values to any revised guidelines.

Technical Report Documentation Page

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4. Title and Subtitle	5. Report Date
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7. Author(s)	8. Performing Organization Report No.
9. Performing Organization Name and Address SHIP RESEARCH COMMITTEE NATIONAL ACADEMY OF SCIENCES 2101 CONSTITUTION AVENUE WASHINGTON, D.C. 20418	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-CG-80356-A ✓
12. Sponsoring Agency Name and Address COMMANDANT (G-DST) U.S. COAST GUARD HEADQUARTERS OFFICE OF RESEARCH AND DEVELOPMENT WASHINGTON, D.C. 20593	13. Type of Report and Period Covered FINAL REPORT 14. Sponsoring Agency Code G-DST-2

15. Supplementary Notes

16. Abstract

The Ship Research Committee (SRC) of the National Research Council provides technical services covering program recommendations, proposal evaluations, and project advice to the interagency Ship Structure Committee (SSC), composed of representatives from the U.S. Coast Guard, the Naval Sea Systems Command, the Military Sealift Command, the Maritime Administration, the American Bureau of Shipping, and the U.S. Geological Survey. This arrangement requires continuing interaction among the SRC, the SSC, the contracting agency, and the project investigators to assure an effective program to improve marine structures through an extension of knowledge of materials, fabrication methods, static and dynamic loading and response, and methods of analysis and design. This report contains the Ship Research Committee's recommended research program for five years, FY 1980-1984, with 13 specific prospectuses for FY 1981. Also included is a brief review of 24 active and 6 recently completed projects.

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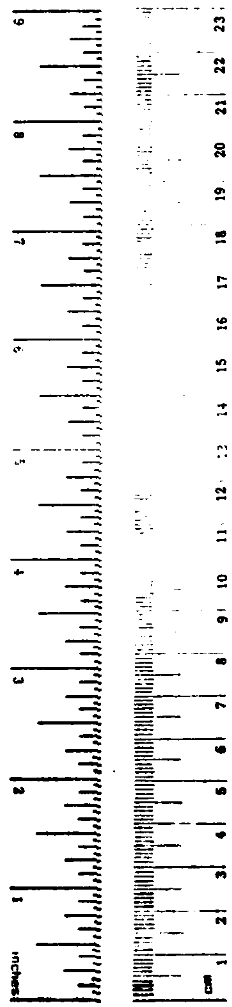
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F